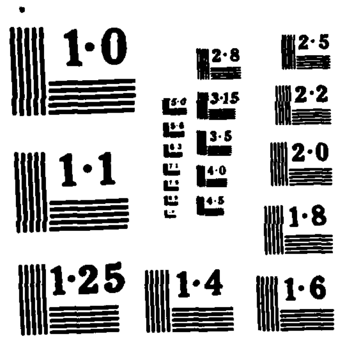
AD-A162 940 EVALUATION OF SEISMOMETER WAVE GAGE AND COMPARATIVE ANALYSIS OF WAVE DATA..(U) COASTAL ENGINEERING RESEARCH CENTER VICKSBURG MS E F THOMPSON ET AL. SEP 85 1/1

UNCLASSIFIED CERC-85-12 F/G 8/11 NL

END

FILMED

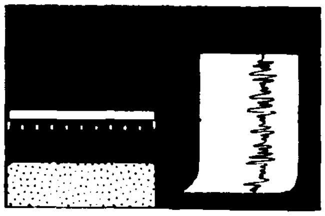
DTIC

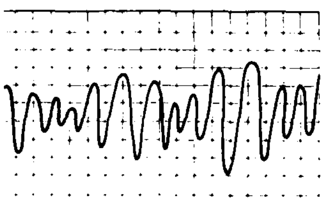


NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

US Army Corps of Engineers

AD-A162 940





12

MISCELLANEOUS PAPER CERC-85-12

EVALUATION OF SEISMOMETER WAVE GAGE AND COMPARATIVE ANALYSIS OF WAVE DATA AT YAQUINA AND COQUILLE BAYS, OREGON

by

Edward F. Thompson, Gary L. Howell, Jane M. Smith

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

September 1985

Final Report

Prepared for

US Army Engineer District, Portland
Portland, Oregon 97208-2946

AD-A162 940

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper CERC-85-12	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EVALUATION OF SEISMOMETER WAVE GAGE AND COMPARATIVE ANALYSIS OF WAVE DATA AT YAQUINA AND COQUILLE BAYS, OREGON		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Edward F. Thompson Gary L. Howell Jane M. Smith		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Coastal Engineering Research Center Geotechnical Laboratory PO Box 631, Vicksburg, Mississippi 39180-0631		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Engineer District, Portland PO Box 2946 Portland, Oregon 97208-2946		12. REPORT DATE September 1985 13. NUMBER OF PAGES 59
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hydrological Forecasting (LC)
Ocean Waves--Measurement (LC)
Oceanographic Instruments (LC)
Seismology--Technological Innovations (LC)
Seismometry (LC)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides a preliminary evaluation of the seismometer wave gage system developed by Oregon State University (OSU). The background and theoretical basis for the OSU system is reviewed. An empirical evaluation is obtained by comparing Yaquina Bay seismometer analyses with data from a pressure gage in the same area during 22 February to 5 March 1984. The pressure gage was funded by the US Army Engineer District, Portland. The OSU

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued).

system appears to be well suited as a sea state indicator for real-time operational purposes. The system has inherent limitations, particularly for estimating wave period. Comparisons with the pressure gage indicate significant wave heights from the seismometer system are relatively reliable. The correlation coefficient is 0.98, and the mean significant heights differ by 8 percent. Suggestions for improving the seismometer system are provided.

The OSU method for analyzing seismometer strip chart records is compared with the Coastal Engineering Research Center (CERC) method developed for this study. The CERC method appears to have small advantages. Guidelines for interpreting past OSU analyses are provided.

A 2-month comparison between the seismometer and a pressure gage near Coquille Bay is also included. This site has the nearest available coastal gage record with longer-term operation. The gage is funded by the Corps of Engineers' Field Data Collection Program. Despite the distance between sites, the comparison is favorable, particularly during high-energy winter wave conditions.

PREFACE

The investigation reported herein was authorized by the US Army Engineer District, Portland (NPP), by Intra-Army Order Number E86840174 dated 22 June 1984. NPP monitors for the study were Messrs. D. Askren and S. A. Chesser. The study was conducted by personnel of the Coastal Engineering Research Center (CERC) and the Geotechnical Laboratory (GL) of the US Army Engineer Waterways Experiment Station (WES), during June 1984 to February 1985.

This report was prepared by Dr. E. F. Thompson, Chief, Coastal Oceanography Branch (COB), Research Division (RD), Mrs. J. M. Smith, COB, RD, and Mr. G. L. Howell, Prototype Measurement and Analysis Branch, Engineering Development Division, CERC. The study was conducted by Dr. Thompson, Mr. Howell, Mrs. Smith, and Ms. P. Rivers of CERC and Mr. R. F. Ballard, Jr., Research Group, GL. The study was done under general supervision of Dr. W. F. Marcuson III, Chief, GL, Dr. J. R. Houston, Chief, Research Division, CERC, and Dr. R. W. Whalin, former Chief, CERC. Mr. Charles C. Calhoun, Jr., is currently Acting Chief, CERC.

Raw seismometer strip chart records and analyses were provided by Mr. H. C. Creech, School of Oceanography, Oregon State University. Insightful comments on the seismometer system were contributed by Professor R. J. Greenfield, Geophysicist, Pennsylvania State University. This report was edited by Ms. Shirley A. J. Hanshaw, Publications and Graphic Arts Division, WES.

COL Tilford C. Creel, CE, and COL Robert C. Lee, CE, were Commanders and Directors of WES during the conduct of the study. COL Allen F. Grum, USA, was Director of WES during the publication of this report. Mr. Fred R. Brown and Dr. Whalin were Technical Directors.

CONTENTS

	Page
PREFACE	1
CONVERSION FACTORS, NON-SI UNITS OF MEASUREMENT TO SI (METRIC) UNITS	3
PART I: INTRODUCTION	4
Background	4
Scope	4
PART II: THEORETICAL BACKGROUND	7
PART III: OSU APPLICATION OF SEISMIC WAVE THEORY	9
Analysis and Comparison of Pressure Gage and Seismometer Gage Data	12
Evaluation of OSU Seismic Wave Monitoring System	13
PART IV: SUGGESTIONS FOR IMPROVING THE SYSTEM	17
PART V: COMPARISON OF OSU AND CERC ANALYSIS METHODS	18
PART VI: COMPARISON OF YAQUINA BAY SEISMOMETER DATA WITH COQUILLE BAY GAGE DATA	21
PART VII: SUMMARY	23
REFERENCES	24
TABLES 1-7	
PLATES 1-26	
APPENDIX A: CERC PROCEDURE FOR ANALYSIS OF WAVE DATA	A1

CONVERSION FACTORS, NON-SI UNITS OF MEASUREMENT TO SI (METRIC) UNITS

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	2.64	centimetres
miles (US statute)	1.609344	kilometres

EVALUATION OF SEISMOMETER WAVE GAGE AND COMPARATIVE ANALYSIS OF WAVE DATA AT YAQUINA AND COQUILLE BAYS, OREGON

PART I: INTRODUCTION

Background

1. The Oregon coast is among the most rugged and high-energy wave coastlines in the contiguous United States. As with other coastlines, it presents formidable obstacles for collection of instrumental wave data. Conventional in situ wave gages historically have been only marginally successful; therefore, alternative wave data gathering techniques have been explored to provide at least an approximate nearshore wave climate. The US Army Engineer District, Portland (NPP), has established and operated a Littoral Environment Observation (LEO) program, with assistance from the Coastal Engineering Research Center (CERC) of the US Army Engineer Waterways Experiment Station (WES), to obtain visual estimates of nearshore breaking waves. Additionally, NPP has requested CERC to evaluate an innovative system developed by Oregon State University (OSU) to derive ocean wave estimates from microseisms sensed by a conventional land-based seismometer. The OSU system has two distinct advantages: (a) it provides instrumentally determined wave estimates, and (b) it allows all equipment to be located in a safe area rather than in the ocean or on the beach. The location of existing seismometer wave gages along the Oregon-Washington coast is shown in Figure 1.

2. The OSU system at Newport, Oregon, near Yaquina Bay, includes a pen-and-ink strip chart recorder. OSU has developed a strip chart data reduction method and used it to analyze and summarize the Yaquina Bay seismometer data collected between 1971 and 1981 (Creech 1981).

Scope

3. Discussed in this report is an evaluation of the OSU seismometer system to aid NPP in interpreting the available wave climatology, in assessing possibilities for analysis of seismometer data collected since 1981, and in evaluating the potential of a seismometer system for future data collection.

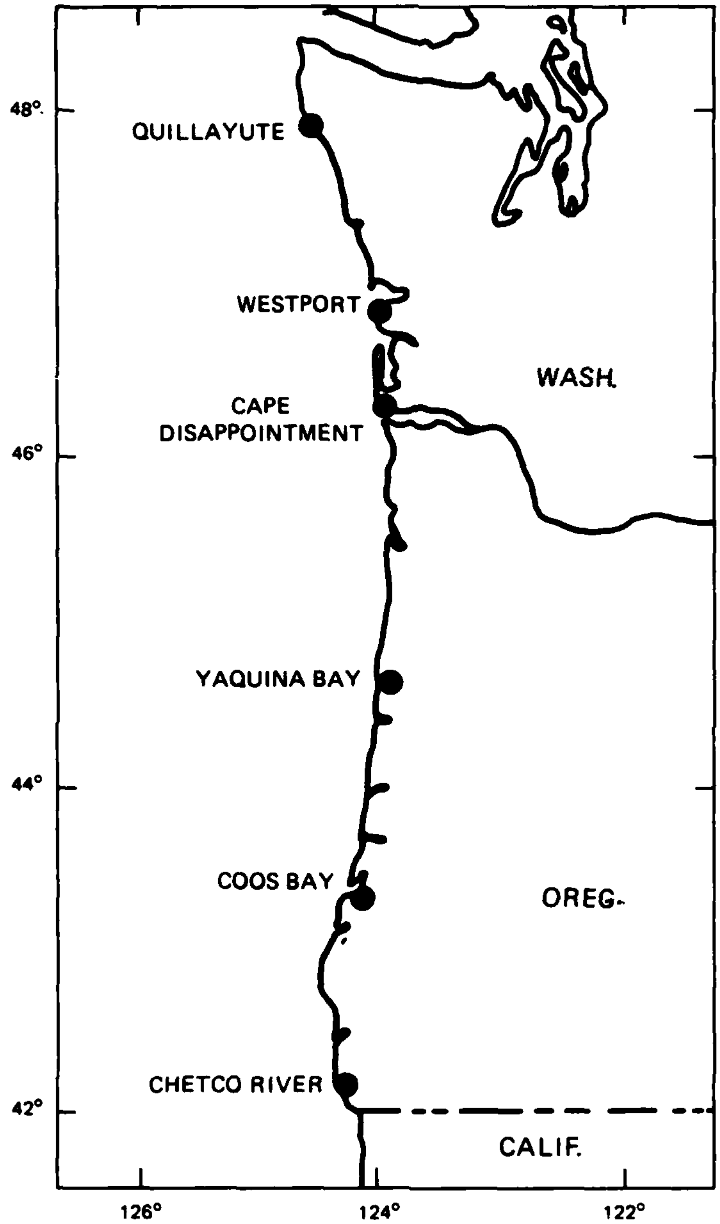


Figure 1. Location of seismometer wave gages along the Oregon-Washington coast

The evaluation is not exhaustive, but it provides the best judgments obtainable within the constraints of the study. The report includes comparative analyses of seismometer and pressure gage data collected by NPP at the entrance to Yaquina Bay (Newport) during 22 February-5 March 1984. The analytical method used for reducing the seismometer data is based on the standard CERC procedure for pen-and-ink strip chart records. For comparison, the OSU and CERC methods were applied for 1 month of relatively low wave conditions (September 1983) and approximately 1 month of relatively high wave conditions (9 February-12 March 1984) at Yaquina Bay. A comparative analysis of Yaquina Bay seismometer data and Coquille Bay pressure gage data is also included. The Coquille bay gage is a long-term operational shallow-water gage along the Oregon coast. The comparisons cover selected months of low and high wave conditions. The Coquille Bay pressure gage is funded by the Corps of Engineers' Field Data Collection Program (FDCP).

PART II: THEORETICAL BACKGROUND

4. A mechanism by which deepwater ocean waves can generate microseisms is described by Longuet-Higgins (1950). The pressure variations under a wave decrease exponentially with depth. However, when two progressive waves of the same wavelength occur together traveling in opposite directions, there is a theoretical prediction for a second order pressure variation which does not attenuate with depth. The variation is proportional to the product of the amplitudes of the two waves and occurs at a frequency twice that of the waves. A comparable situation in nature could occur when waves approach a coastline and are partially reflected such that the reflected waves interact with additional incoming waves with similar frequencies.

5. Hasselmann (1963) significantly extended the theoretical basis by considering spectral transfer functions and the local energy balance equation of the seismic field. He found that microseisms are effectively excited only by components of the pressure spectrum that have the same phase velocities as free seismic waves. These velocities are very high relative to typical ocean wave phase velocities. However, the phase velocity associated with second-order pressure variations is comparable to seismic wave phase velocities. Thus, the second order pressure variation is expected to be effective at exciting seismic wave energy both because it extends to the ocean bottom, even in deep water, and because it matches the seismic waves in phase velocity. Hasselmann also indicated that a broad spectrum of ocean wave energy generated by a storm in deep water near the coast may be expected to give a stronger seismic signal than if the storm were located over the continental shelf. A narrow spectrum is expected to generate seismic waves more effectively on the shelf than in deep water.

6. Hasselmann's (1963) analysis for ocean waves over a sloping shallow bottom indicates that appreciable seismic energy can be generated also at incident wave frequencies. Microseismic energy is found to decrease rapidly with increasing frequency. Thus, low-frequency incident waves may be expected to be most effective in generating microseismic waves of comparable frequency.

7. Haubrich, Munk, and Snodgrass (1963) analyzed low-frequency ocean swell wave and seismic recordings near San Diego, California. Peaks in the seismic spectra were visible at both the peak ocean wave frequency f_p and at $2f_p$. The peak at $2f_p$ contained approximately 100 times as much energy as

the peak at f_p They suggested that the microseisms were generated in a coastal strip, approximately 100 miles* long, centered on the coastal point opposite the seismometer. They suggested the generative strip was confined to shallow water for seismic waves at primary frequencies and extended 200 miles seaward for waves at double frequencies. Generative strips at these scales can be visualized in Figure 1 by noting that the distance between Newport and Coos Bay is approximately 100 miles. The width of the coastal strip is expected to be smaller for distant, compact, and short-lived storms and greater for nearby storms of large size and duration. Only seismic waves approaching approximately normal to shore will arrive at a land-based seismometer since refraction induced by phase velocity differences between continental and oceanic regions will turn obliquely incident seismic waves back toward the sea. Thus, ocean waves approaching normal to shore should be stronger microseism generators than waves approaching at large oblique angles.

---

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

PART III: OSU APPLICATION OF SEISMIC WAVE THEORY

8. OSU (Zopf, Creech, and Quinn 1976) has adapted the theory of the origin of microseisms to obtain estimates of ocean wave significant height and period from land-based seismometer measurements. Longuet-Higgins' (1950) analysis for two progressive waves moving in opposite directions indicates that

$$p = C_1 a^2 \omega^2 \cos (2\omega t) \tag{1}$$

where

p = mean pressure fluctuation on the sea floor

C_1 = proportionality constant

a = wave amplitude

ω = wave frequency = $2\pi/T$ where T is the wave period

t = time

The amplitude of the seismic waves a_{seis} is assumed to be proportional to the mean pressure fluctuation. Thus,

$$a_{seis} = C_2 p = C_1 C_2 a^2 \omega^2 \cos (2\omega t) \tag{2}$$

The velocity record v_{seis} of the seismic waves is then assumed to be the time derivative of a_{seis}, or

$$v_{seis} = C_1 C_2 C_3 a^2 \omega^3 \sin (2\omega t) \tag{3}$$

9. The velocity record, retained on pen-and-ink strip charts for the Yaquina Bay site, is analyzed as if it were a record of surface wave elevations. The result is corrected for seismometer response by using the following relationship from Equation 3:

$$H_{seis} = K \frac{H_{ocean}^2}{T_{seis}^3} \tag{4}$$

where

H_{seis} = height parameter obtained by analyzing seismometer record

K = constant

H_{ocean} = ocean wave height

T_{seis} = period parameter obtained by analyzing seismometer record

The constant K embodies all proportionality constants from previous equations.

10. A Teledyne-Geotech Model SL-210 seismometer is used. The signal is modified by a low pass filter with a break point at 0.7 Hz to eliminate ambient seismic noise. Another filter with a response proportional to $1/\omega^3$ between 0.1 and 0.4 Hz is used to remove the dependence of H_{seis} on $1/T^3_{seis}$ (Equation 4). Thus, in the filtered signal

$$H_{seis} = KH^2_{ocean} \tag{5}$$

11. The constant K in Equation 5 is determined empirically at each seismometer site by estimating seismometer wave height and ocean wave height simultaneously. At Yaquina Bay, the seismometer height was taken as the height of the larger waves in the 10-min record and was assumed to represent the average height of the 0.10 highest waves. The ocean wave period is estimated for the seismometer record as twice the average zero-crossing period of the record. The ocean wave height and period were estimated by using binoculars to observe for 10 min a 12-ft-high buoy moored 40 ft deep 2 miles from shore. The observer estimated the average h ight of the highest 10 percent of the waves. A few pressure sensor and fathometer wave estimates taken from the OSU research vessel Paiute were also used. A scatter plot of the height results is given in Figure 2. The correlation coefficient was 0.87.

12. The general concept of the seismic wave monitoring system is to provide wave estimates as a solution to a type of inverse scattering problem. The performance and accuracy of the gage are directly related to how well the relevant statistics (wave height and period) of a directional ocean wave field can be determined by a nondirectional measurement of the seismic wave field, which is related to the ocean wave field through a series of physical processes. The chain of processes can be summarized as follows:

a. The surface wind wave spectrum in shallow coastal water (40-ft depth).

b. The surface wind wave spectrum in deep water.

c. The reflected or otherwise generated opposite velocity components of the surface spectrum.

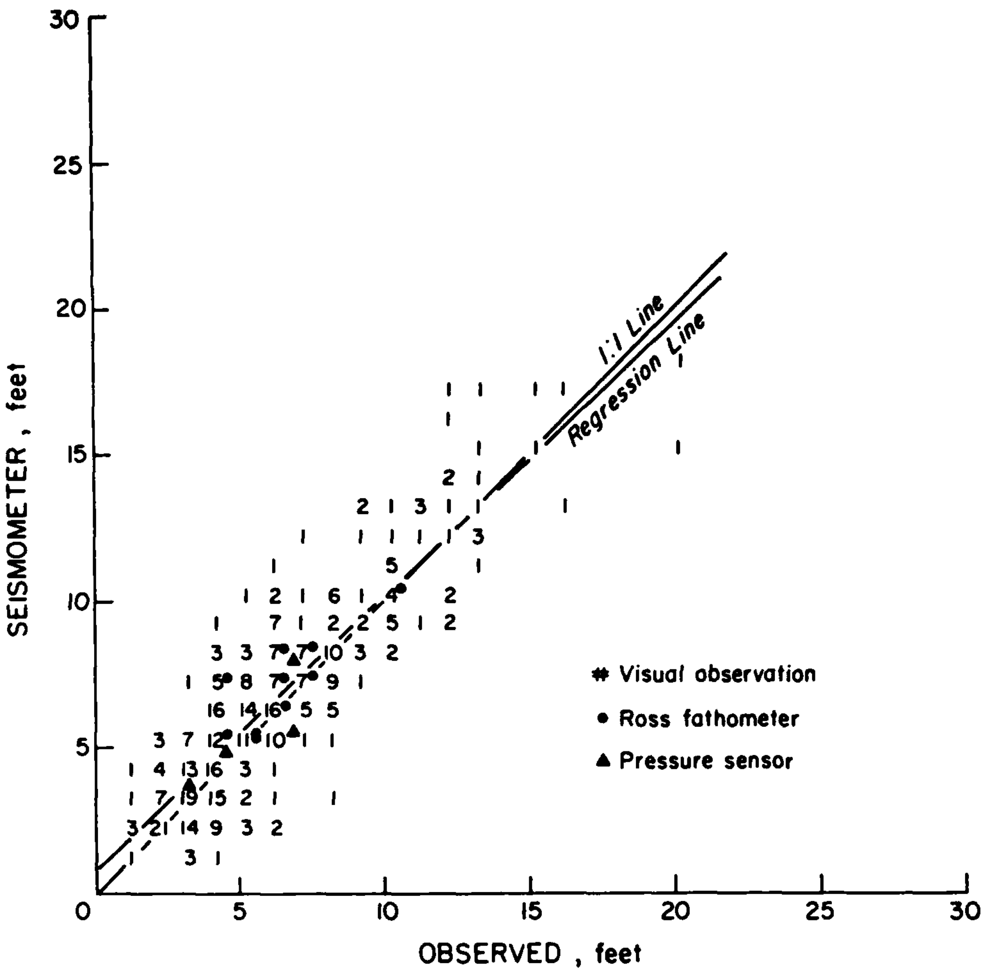


Figure 2. Significant wave height data used to calibrate seismometer gage at Yaquina Bay, Oregon (from Creech 1981)

d. The resulting standing wave field.

e. The resulting unattenuated standing wave pressure field on the bottom.

f. The generation and propagation of microseisms due to the pressure field.

g. The measurement of a scalar value of ground motion due to the superposition of wave generated microseisms and other sources of seismic activity.

13. The inverse problem is to create an inverse physical model of the generation process, drive the model with the measur:d scalar value g , and obtain an estimate of the desired statistics of the wave spectrum a .

Analysis and Comparison of Pressure Gage and Seismometer Gage Data

14. Directional wave analyses from a co-located pressure gage and pair of orthogonal current meters in the horizontal plane were prepared by OSU (Sollitt and Standley 1984) and furnished to CERC by NPP. The gage installation and data analyses were funded by NPP. The gages were bottom-mounted in 100-ft water depth off the entrance to Yaquina Bay. Significant height was estimated as four times the square root of the total energy in the directional spectrum. The duration of gage operation was 22 February-5 March 1984. Analyses were provided for 59 percent (41 observations) of the possible observations taken every 4 hr. An observation is missed whenever the time series has missing data points. Some of the sequences of missing data points are short and can be reconstructed by interpolation. Thus, additional pressure gage analyses can abe extracted if desired, but the reconstruction and reanalysis effort was beyond the scope of this study. All gaps are shorter than 1 day. The OSU digital analysis procedure was designed to compensate for the natural filtering of high-frequency energy at 100-ft depth so that results represent surface wave conditions. Energy at periods shorter than approximately 6.3 sec is attenuated beyond recovery.

15. Strip chart records from the seismometer gage at Yaquina Bay were provided CERC by OSU. A method for the present analysis was developed at CERC based on the most successful CERC method for manual analysis of strip chart records of sea surface elevation. Described in Appendix A, the method applied to the seismometer records was used to estimate significant wave height and period for data collected during the period of operation of the NPP gages. Analyses were performed for 95 percent (98 observations) of the possible observations taken every 3 hr. Several records could not be analyzed because the trace went continually offscale. Some of these were due to earthquakes. Because of the dependence of the seismic signal on ocean wave height squared (Equation 5), small increases in height during a high-energy ocean environment cause dramatic increases in the excursions of the seismometer trace.

16. A time-history of significant wave height from the seismometer and pressure gage is given in Plate 1. A similar comparison of significant wave period is given in Plate 2. Periods for the pressure gage represent the reciprocal of the peak frequency of the directional spectrum. Scatter plots of

seismometer versus pressure gage parameters are given in Plates 3 and 4. Seismometer and pressure gage observations were paired to be, at most, 1 hr apart. Results of one- and two-parameter linear regression analyses are listed, and the two-parameter regression line is plotted. The two-parameter regression line calculated by Creech (1981) is also plotted in Plate 3. The 45-deg line along which seismometer and pressure gage estimates would be equal is shown in both plates. Statistics of the data are given in Tables 1 and 2. The correlation coefficient between heights is 0.98; between per'~ds it is 0.72.

Evaluation of OSU Seismic Wave Monitoring System

17. A preliminary evaluation of the OSU seismic wave monitoring system has been prepared as a joint effort by CERC and the Geotechnical Laboratory at WES, with input from Professor R. J. Greenfield, Geophysicist, Pennsylvania State University. The evaluation is based primarily on published information about the system, as funds did not allow for a detailed investigation or inspection of the construction, installation, and operation of the system.

Limitations

18. The seismometer and recorder used in the evaluation are standard instruments in the seismological profession and have proven to be reliable and accurate for microseismic studies. However, the analog electronic filter used may be very sensitive to temperature fluctuations. The electronic filter employed is a three-pole, low-pass active filter realized by one simple pole and a complex conjugate pair. Because the design of the filter does not sufficiently isolate the two stages, it is difficult to analyze exactly the response of the filter without use of a simple computer program. Such analysis has not been done at this preliminary stage. However, some general conclusions about the response can be made. The design appears to use low-pass frequency break points which are very low compared to the anticipated range of double frequencies to guarantee that the frequencies of interest are in the log linear $1/\omega^3$ range of the response curve.

19. One potential problem with the filter is that the strategy mentioned above makes the actual gain of the filter at each frequency a function of the breakpoint frequency. In fact, the gain change will be proportional to the third power of break point shift. The sensitivity of this filter

implementation to shift of breakpoint with change of capacitor value is fairly high ($s = 1$ for the simple pole and $s = 0.5$ for each of the capacitors in the pole pair circuit). Since the size of capacitors used to achieve the low break frequencies is quite large, it is likely they will have very poor temperature coefficients. The result of all of these factors is that the filter gain characteristics as a function of wave period could be very sensitive to temperature fluctuations. The seismometer system is housed in a temperature-controlled room, but small temperature fluctuations may still occur and have an effect on readings. The importance of this effect can be assessed only by further investigation.

20. Another potential problem with the filter is that the phase characteristics may cause severe distortion of wave forms resulting from a range of closely spaced frequencies such as waves. This distortion would manifest itself in groups which, while having the correct total energy, will have peaks and zero-crossing periods which may be significantly displaced from their unfiltered values. This effect has implications for the type of analysis presently performed on the strip chart records to obtain height and period information. Quantification of the effects and errors would require additional analysis.

21. Problems relative to the general inverse scattering model are a major concern. The inverse model used to estimate ocean waves from microseisms is very simple in comparison with the complexity of the physical generation process. Specific areas of concern are the following:

a. Lack of consideration of microseismic activity with period equal to the ocean wave periods. The filtering used in the OSU system would cause overemphasis of existing energy at primary frequencies, although it may still be small relative to energy at the double frequencies.

b. Lack of consideration of the large area in which microseisms are generated.

c. Lack of consideration of natural factors which may be expected to cause the constant K in Equation 5 to vary.

22. Relative to item c, the value of K depends on the geologic structure in the deepwater areas where the seismic waves are generated, the propagation path of the Rayleigh seismic waves, and the geologic structure at the seismometer. Further, ocean wave reflection in shallow water is influenced by shallow-water wave transformation processes, nearshore bathymetry, and nearshore currents. Thus K at a particular site may be expected to have some

dependence on the following attributes of the deepwater ocean waves: energy, peak frequency, approach direction, directional spread of energy, and spectral wid i. Additional factors affecting K may be nearshore winds (noted by Zopf, Creech, nd Quinn 1976); nearshore currents; presence of more than one con urrent ocean wave tr in; and characteristics of nearshore storms, including storm size di tance from coast, and storm movement.

Usefulness

23. Despite the limitations of the OSU system, the comparisons with nearshore data at Yaquina Bay presented by Zopf, Creech and Quinn (1976) and in this report indicate that it provides useful estimates of nearshore significant wave height. The estimates are particularly satisfactory for real-time operational purposes. Significant heights from the OSU system compare well with pressure gage analyses for the 12-day data set, with a correlation of 0.98 between them. Wave period estimates from the OSU system show a weak overall correlation of 0.72 with pressure gage data and appear to have limited application for practical engineering work.

24. The comparison of wave periods is strongly affected by the presence of prominent secondary wave trains as evidenced by secondary peaks in the spectrum. Occasional large, erratic shifts in peak spectral period from the pressure gage in Plate 1 are a direct result of the presence of two wave trains with comparable peak energy but widely differing peak frequencies. The seismometer strip chart analysis method can provide only a single estimate of period. As expected, the data indicate that the seismometer period is intermediate to the two prominent periods actually present in the ocean. This point is illustrated in Plate 2 between day markers 1 and 3. The spectra show prominent peaks at approximately 11 and 17 sec, while the seismometer gives approximately 14-sec periods. Overall, more than two-thirds of the pressure gage spectra show more than one prominent peak.

25. If only the single-peaked spectral cases are considered, the comparison between seismometer and pressure gage periods is significantly improved in this small data set. Linear regression analysis results are given in Plates 5 (dashed line with dots representing the regression line from Figure 2) and 6 (including only cases with single peaked spectra). The correlation is 0.98 for heights. For periods, the scatter of data points in Plate 6 is considerably less than that in Plate 4 despite comparable correlation coefficients. The relatively low correlation of 0.71 for periods in Plate 6

appears to be a consequence of the very small range of periods represented in the data rather than poor agreement between seismometer and pressure gage periods. A total of 13 single-peaked cases was available. Statistics for the seismometer and pressure data are very similar in this case (Tables 3 and 4). Mean period is the same from both gages to the nearest 0.1 sec which further substantiates improved agreement between seismometer and pressure gage when only single-peaked cases are considered.

26. A tendency for the seismometer to overestimate significant height for relatively low-wave conditions is evident in Plates 1 and 3. No strong dependence of the seismometer-pressure gage comparison on peak frequency, approach direction, directional spread of energy, or current speed and direction has been identified in the limited data set. A significantly longer data set (on the order of 6 months long) would be needed to carefully assess these effects.

27. The effect of water depth on the comparison was considered. The seismometer was calibrated for wave conditions in 40-ft depth, while the pressure gage represents conditions in approximately 100-ft depth. Three pressure gage observations during the highest wave conditions were modeled as JONSWAP spectra with appropriate energy and peak frequency and transformed from 100- to 40-ft depth. The transformation model is based on the assumption of a cosine squared directional spread of energy, a Kitaigorodskii limiting form for the shallow-water spectrum, and straight parallel bottom contours. A decrease in significant wave height from 1 to 2 ft was predicted by the model. Most, if not all, of the observations in this data set represent predominant swell conditions, and the Kitaigorodskii spectral form applies only for locally generated spectra (spectra with fully saturated high-frequency tails). Therefore, extensive use of the simple transformation model with the present data set is not warranted.

PART IV: SUGGESTIONS FOR IMPROVING THE SYSTEM

28. During the course of the evaluation of the OSU seismometer system, the following suggestions for improving the system were developed:

- a. Eliminate the analog electronic filter and record and analyze data in digital form with an on-site microcomputer. Costs to convert to a microcomputer system are expected to be on the order of $25,000 for development and $5,000-$8,000 per site for implementation.
- b. As an alternative to suggestion a, analyze in detail the analog electronic filter and redesign if warranted. Suggestion a is preferable for a fully-supported program to collect future data, but b would be helpful for interpreting existing data. Costs to implement b have not been estimated.
- c. Investigate the possibility of using the primary frequency and its energy, rather than the double frequency, to estimate coastal ocean wave parameters. This approach, in theory, would be based on seismic energy generated only in shallow water in a localized coastal area rather than an area extending several hundred miles seaward from shore. Since energy at the double frequency is expected to be 100 times more than at the primary frequency, digital analysis methods would be required.
- d. Develop a better inverse model. For example, the possibility of grouping the observations used for calibration into several ranges of wave period and determining a value of the constant K in Equation 5 for each period range could be investigated. This approach may be preferable to assuming the period dependence as given in Equation 4.
- e. Investigate the possibility of identifying multiple prominent wave trains in a record when they occur. Digital analysis methods would be required.

PART V: COMPARISON OF OSU AND CERC ANALYSIS METHODS

29. OSU has collected seismometer data from Yaquina Bay for November 1971 to the present. The data from 1971-1981 were analyzed by a method devised by OSU to give estimates of significant wave height and period. It was assumed that the larger waves in a record approximate the average height of the 10 percent highest waves. This representative height is measured from the record using a transparent template (Figure A2). The measured height is then multiplied by 0.8 to give an estimate of the significant height in accordance with the assumption of a Rayleigh distribution of wave heights (Longuet-Higgins 1952).

30. Since 1977, significant wave period by the OSU method has been estimated from the ratio of record length to the number of zero-crossing waves in the 10-min record. This average zero-crossing period is multipled by two to approximate ocean wave periods. Prior to 1977 a different method was used to estimate significant period because of the limitations of the recorded data. Significant period was estimated as the average period of the few highest waves in the record (Zopf, Creech, and Quinn 1976).

31. An intercomparison between the CERC and OSU analysis methods and comparison of data from both methods with the NPP measurements was conducted. Results are helpful in assessing the choices for reducing the presently unanalyzed Yaquina Bay data from 1981-1984 as well as in interpreting pre-1981 results already available. Two months of recent data were selected for analysis. One month (September 1983) was selected as representative of the relatively low-energy wave season and the other month (9 February-12 March 1984) represented the high-energy wave season. Data were collected at 6-hr intervals except for the special 3-hr interval implemented during the time of NPP gage operation.

32. Regression analysis for seismometer data (OSU analysis) and NPP measurements paired to be within 1 hr of each other are summarized in Plates 7-10 and Table 5. The OSU significant wave heights are generally higher than the NPP heights with the important exception of the highest storm episode. The mean OSU wave height is 7 percent higher than the mean NPP wave height. There is a high correlation of 0.98 between heights. The OSU significant wave period tends to be longer than the NPP period. The mean OSU period is 9 percent longer than the mean NPP period. The correlation between periods, 0.77, is moderate.

33. Regression analyses for seismometer data analyzed by the CERC and OSU methods are given in Plates 11-14 for September 1983, in Plates 15-18 for February-March 1984, and in Table 6 for September 1983 and February-March 1984. The results indicate relatively close agreement between the two analysis methods for wave heights. The OSU data show a small tendency to be higher than the CERC data, except during the highest winter wave conditions. The OSU mean exceeds the CERC mean by approximately 5 percent in September. The means are within 1 percent of each other for the winter month. Correlations are high for the winter month and moderate for September. The tendency for OSU data to be lower than those of CERC for high wave conditions is particularly evident for the most severe storm during the episode, in that the CERC estimate during the storm peak was 2.9 ft higher than the OSU estimate.

34. The OSU wave period estimates show a consistent tendency to be longer than the CERC estimates. The mean OSU wave period is longer than the mean CERC period by approximately 20 percent for September and 10 percent for the winter month. Correlations are moderately high. The difference between mean period in September and February-March is 0.8 sec for OSU and 1.8 sec for CERC.

35. The overall differences between the OSU and CERC methods for wave height analysis are small. The CERC method is more objective than the OSU method, and it should be more definitive. The CERC method is preferable for analysis of high-energy wave conditions, whereas the OSU method shows an undesirable tendency to underestimate significant wave height. It is also expected that the quality of results from the OSU method is more dependent upon the judgment and experience of the person performing the analysis than it is for the CERC method. However, the OSU method has the obvious and important advantage of being quicker and less tedious than the CERC method. The OSU method requires measurement of one wave height per record, while the CERC method requires measurement of typically three or four wave heights.

36. The OSU method for significant wave periods appears to have a consistent bias toward long periods, while the CERC method indicates a small bias toward short periods. The CERC method shows more seasonal variability in wave periods. The CERC method for periods is significantly quicker and easier to apply than the OSU method. The resolution of the CERC method in this application is significantly limited by the slow chart speed. Although the CERC method for period appears to be more subjective than the OSU method, that is

not always the case. The selection of zero-crossing waves required by the OSU method is not always straightforward and is sometimes impossible for very low wave conditions.

37. Differences in wave period definitions should be considered also. The CERC method has been previously shown to give periods which are approximately 5 percent shorter than peak spectral periods for exposed ocean sites (Thompson 1977). This is consistent with the differences observed at Yaquina Bay. The relationship between mean zero-crossing period in the OSU method and peak spectral period is not easily specified because it depends on spectral shape. Qualitatively, the mean zero-crossing period is expected to be somewhat shorter than the CERC period because of a weak tendency for lower waves to have shorter periods. Since the data show the reverse tendency, it is evident that manually determined mean zero-crossing periods from seismometer strip charts in which low waves are highly attenuated in comparison to high waves (because of the height squared dependence in Equation 5) are not equivalent to mean zero-crossing periods from ocean wave records.

38. The long-term wave statistics already published by OSU certainly appear to be a useful record of wave climate. It is recommended, however, that the statistics be used with the following caveats:

- a. Significant wave heights higher than 12 ft may be underestimated. NPP should consider reanalyzing the post-1977 cases by the CERC method if the statistics are to be used for design.
- b. Significant wave periods during the winter months may be too long by about 10 percent for the post-1977 data.
- c. Significant wave periods during the summer months are not recommended for use. Periods from the spring and fall months should be used with care if at all.

39. For analysis of existing seismometer data collected between 1981 and 1984, it is recommended that the CERC method be used. Climatological results from this effort would be helpful also in assessing the statistical reliability of the 1971-1981 results. If seismometer strip chart data are to be collected and analyzed in the future, it is recommended that a faster chart speed be used so that the CERC method can better distinguish wave period. However, if future operation of seismometer gages is to be funded, a modernized data recording and analysis system is strongly recommended for consideration.

PART VI: COMPARISON OF YAQUINA BAY SEISMOMETER DATA WITH COQUILLE BAY GAGE DATA

40. Data from the Yaquina Bay seismometer analyzed by the CERC method were compared with data from an FDCP pressure gage at Coquille Bay for the same 2-month period. The pressure gage is located in 40-ft water depth; therefore, no shoaling correction was necessary. No wave direction information is available. Any differences in exposure and offshore bottom contours between the sites have been ignored, although these differences are not known to be major. Pressure gage data were obtained from monthly data summaries published jointly by the Corps of Engineers and the State of California Department of Boating and Waterways. Significant period was taken from the summaries as the midperiod of the spectral band containing the most energy. It is important to note that this period in some cases may not represent the customary band of maximum energy density because the printed spectral bands have nonuniform frequency widths.

41. Regression analyses (Plates 19-22 and Table 7) for data paired within 2 hr from September 1983 show a clear tendency for the seismometer significant wave heights to be less than the Coquille Bay heights. The mean seismometer height is 40 percent less than the mean Coquille Bay height. Despite the significant difference in magnitudes, the heights from both sites follow a similar pattern; that is, significant increases and decreases in height occur at both sites at about the same times. The correlation coefficient is 0.81. The wave periods at the seismometer are longer than those at Coquille Bay in almost all cases. Mean periods differ by 3.3 sec or 39 percent.

42. Analyses for the winter month (Plates 23-26 and Table 7) show a remarkable agreement between heights, especially for the higher wave conditions. There is a tendency for the seismometer heights to fall above Coquille Bay heights for the lower wave conditions. The overall mean height for the seismometer is 0.5 ft, or 6 percent higher than the mean at Coquille Bay. The agreement between periods is also remarkable. The overall mean periods from both sites are virtually identical.

43. Synoptic weather maps were obtained and reviewed for the winter month. Storm systems were all large compared to the scale of the distance between Yaquina Bay and Coquille Bay. Also, they indicated relative uniformity in wave-generating wind conditions affecting the Oregon coast. Hence, it is

reasonable that storm waves would be related at the two sites.

44. Even considering the large-scale storm systems and the spatially integrated nature of the seismic signal, the agreement between heights and periods for the winter month is remarkable. There is a very close resemblance between the scatter and regression parameters in Plate 25 and the seismometer versus gage comparison at Yaquina Bay (Plate 9).

45. In conclusion, the Yaquina Bay seismometer appears to be a good predictor of wave conditions in similar depth at Coquille Bay for the winter season. The agreement between heights and periods at the two sites during the summer is substantially less satisfactory, as might be expected due to the lower wave conditions and more localized wind events.

PART VII: SUMMARY

46. Based on a limited study, the OSU seismometer system appears to be well suited for its original purpose as a sea state indicator for real-time operational purposes. The system requires minimal maintenance and is reliable except for occasional bad records due to earthquakes or strong offshore winds.

47. The system has inherent limitations relative to the accuracy of wave parameters because it is based on solving an inverse scattering problem using a highly simplified model. In comparison with data from the NPP pressure gage at Yaquina Bay, accuracy limitations on significant wave height from the seismometer system are minor, appearing only as a small scatter with no strong bias. Significant period estimates from the seismometer system show a weak correlation with periods from the pressure gage. If only single-peaked spectral cases are considered, the comparison between periods is significantly improved. Since multi-peaked spectra appear to be more common than single-peaked spectra along the Oregon coast, the present seismometer system is limited in its capability for estimating wave periods. Suggestions for improving the system are provided.

48. Comparison of the OSU method for strip chart analysis with data from the NPP pressure gage and with the CERC method indicates comparable wave height results for most wave conditions but a tendency for the OSU method to underestimate significant wave heights during high wave conditions. Wave periods by the OSU method appear to be useful for winter wave conditions, although biased toward long periods. OSU wave periods for summer wave conditions are not recommended for use. Guidelines for interpreting past OSU analyses are provided.

49. The Yaquina Bay seismometer and Coquille Bay pressure gage give remarkably similar significant heights and periods for the winter month considered. The comparison during the summer month is less satisfactory, as might be expected due to lower wave conditions and more localized wind events.

50. The preliminary evaluation given in this report is based on the best judgments obtainable within the financial constraints of the study. It is not exhaustive. Further study would be required for a definitive evaluation of the OSU seismometer system.

REFERENCES

Creech, H. C. 1981. "Nearshore Wave Climatology, Yaquina Bay, Oregon (1971-1981," ORESU-T-81-002, Oregon State University Sea Grant College Program, Oregon State University, Corvallis, Oreg.

Hasselmann, K. 1963. "A Statistical Analysis of the Generation of Microseisms," Review of Geophysics, Vol 1, No. 2, pp 177-210.

Hautrich, R. A., Munk, W. H., and Snodgrass, F. E. 1963. "Comparative Spectra of Microseisms and Swell," Bulletin of the Seismological Society of America, Vol 53, No. 1, pp 27-37.

Longuet-Higgins, M. S. 1950. "A Theory of the Origin of Microseisms," Transactions of the Royal Society (London), Series A, Vol 243, pp 1-35.

Longuet-Higgins, M. S. 1952. "On the Statistical Distribution of the Heights of Sea Waves," Journal of Marine Research, Vol 11, No. 3, pp 245-266.

Sollitt, C. K., and Standley, D. R. 1984. "Vector Averaged Currents and Directional Spectra, Offshore Newport, Oregon, February 22-March 5, 1984," Oregon State University Wave Research Laboratory, Oregon State University, Corvallis, Oreg.

Thompson, E. F. 1977. "Wave Climate at Selected Locations Along U. S. Coasts," CERC TR 77-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Zopf, D. O., Creech, H. C., and Quinn, W. H. 1976. "The Wavemeter: A Land-Based System for Measuring Nearshore Ocean Waves," Marine Technology Society Journal, Vol 10, No. 4, pp 19-25.

Table 1

Significant Wave Height Statistics from 41 Paired Observations at NPP Pressure Gage and Seismometer 22 February-5 March 1984

Instrument	Mean ft	Standard Deviation ft	Coefficient of Variation*
Seismometer**	8.87	3.67	0.41
Pressure gage	8.18	3.87	0.47

* Ratio of standard deviation to mean.
** Analyzed by CERC method.

Table 2

Significant Wave Period Statistics from 41 Paired Observations at NPP Pressure Gage and Seismometer 22 February-5 March 1984

Instrument	Mean sec	Standard Deviation sec	Coefficient of Variation
Seismometer*	12.88	1.33	0.10
Pressure gage	13.32	2.44	0.18

* Analyzed by CERC method.

Table 3

Significant Wave Height Statistics from 13 Paired Observations for Cases with Single-Peaked Spectra at NPP Pressure Gage, 22 February-5 March 1984

Instrument	Mean ft	Standard Deviation ft	Coefficient of Variation
Seismometer*	8.50	2.66	0.31
Pressure gage	8.36	2.97	0.36

* Analyzed by CERC method.

Table 4

Significant Wave Period Statistics from 13 Paired Observations for Cases with Single-Peaked Spectra at NPP Pressure Gage, 22 February-5 March 1984

Instrument	Mean sec	Standard Deviation sec	Coefficient of Variation
Seismometer*	12.31	1.11	0.09
Pressure gage	12.33	0.97	0.08

* Analyzed by CERC method.

Table 5

Significant Wave Statistics from Paired Observations at NPP Pressure Gage and at Seismometer Gage Analyzed by OSU and CERC Methods, 22 February-5 March 1984, 41 Observations

Instrument	Mean ft	Standard Deviation ft	Coefficient of Variation	Correlation Coefficient with NPP Gage	Deviation of Mean from NPP Gage %	Deviation of Mean from CERC Method %
			Wave Height			
OSU seismometer	8.76	3.32	0.38	0.98	+7	-1
CERC seismometer	8.87	3.67	0.41	0.98	+8	--
NPP gage	8.18	3.87	0.47	--	--	--
			Wave Period			
OSU seismometer	14.48	1.40	0.10	0.77	+9	+12
CERC seismometer	12.88	1.33	0.10	0.72	-3	
NPP gage	13.32	2.44	0.18	--	--	--

Table 6

Significant Wave Statistics from Seismometer Gage

Analyzed by OSU and CERC Methods

	Mean		Standard Deviation		Coefficient of Variation		Correlation Coefficient		Deviation of Mean from CERC Method		
Method	Height ft	Period sec	Height ft	Period sec	Height	Period	Height	Period	Height %	Period %	Number of Observations
					1-30 September 1983						
OSU	3.20	13.85	1.24	2.08	0.39	0.15	0.98	0.77	+5	+20	114*
CERC	3.04	11.56	1.08	0.95	0.36	0.08	--	--	--	--	114
					9 February-12 March 1984						
OSU	8.82	14.64	2.72	1.54	0.31	0.11	0.98	0.80	-1	+10	205
CERC	8.88	13.36	3.08	1.41	0.35	0.11	--	--	--	--	205

* The number of wave period observations from the OSU method is 107. Average zero-crossing periods could not be determined for the lowest wave conditions.

Table 7

Significant Wave Statistics from Paired Observations at Yaquina Bay

Seismometer Gage and FDCP Coquille Bay Pressure Gage

Method	Mean		Standard Deviation		Coefficient of Variation		Correlation Coefficient		Deviation of Mean from CERC Method		Number of Observations
	Height ft	Period sec	Height ft	Period sec	Height	Period	Height	Period	Height %	Period %	
					1-30 September 1983						
Seismometer*	3.06	11.55	1.08	0.95	0.35	0.08	0.81	0.50	-40	+39	110
FDCP	5.13	8.29	2.08	2.24	0.41	0.27	--	--	--	--	110
					9 February-12 March 1984						
Seismometer*	9.22	13.34	3.04	1.39	0.33	0.10	0.94	0.72	+6	0	123
FDCP	8.70	13.36	3.63	2.63	0.42	0.20	--	--	--	--	123

*Analyzed by CERC method.

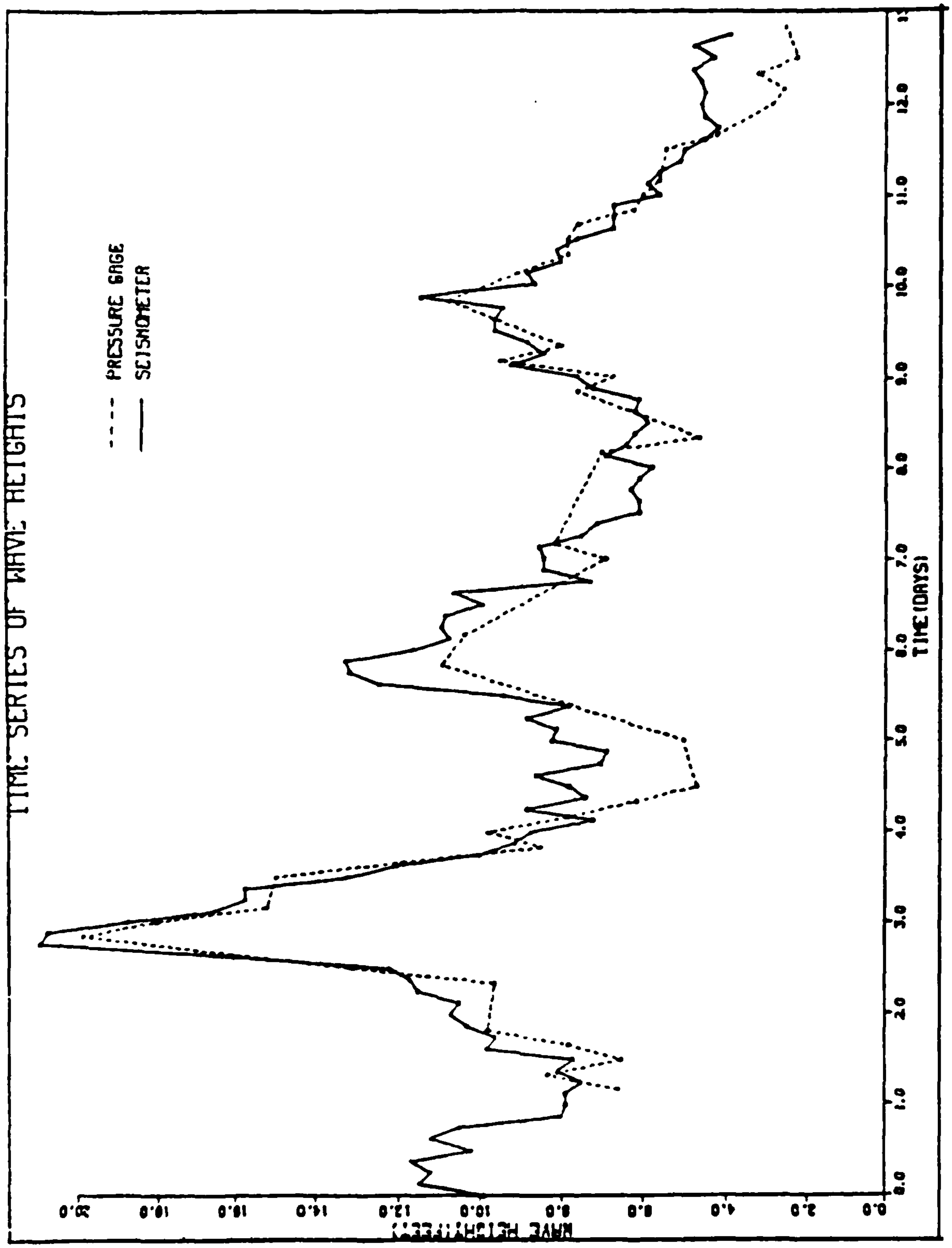

TIME SERIES OF WAVE HEIGHTS
PRESSURE GAGE
SEISMOMETER
TIME(DAYS)
WAVE HEIGHT(FEET)

PLATE 1

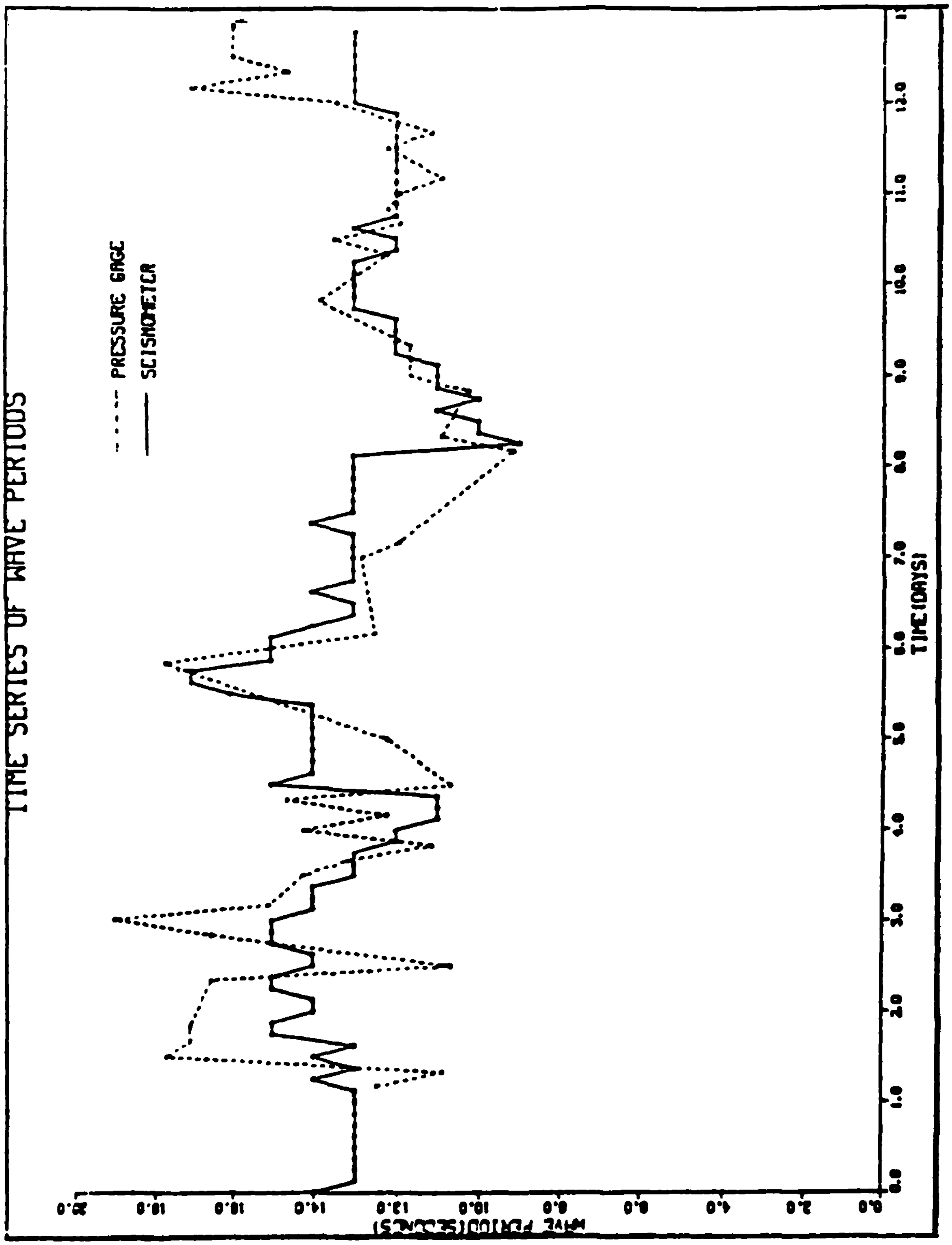
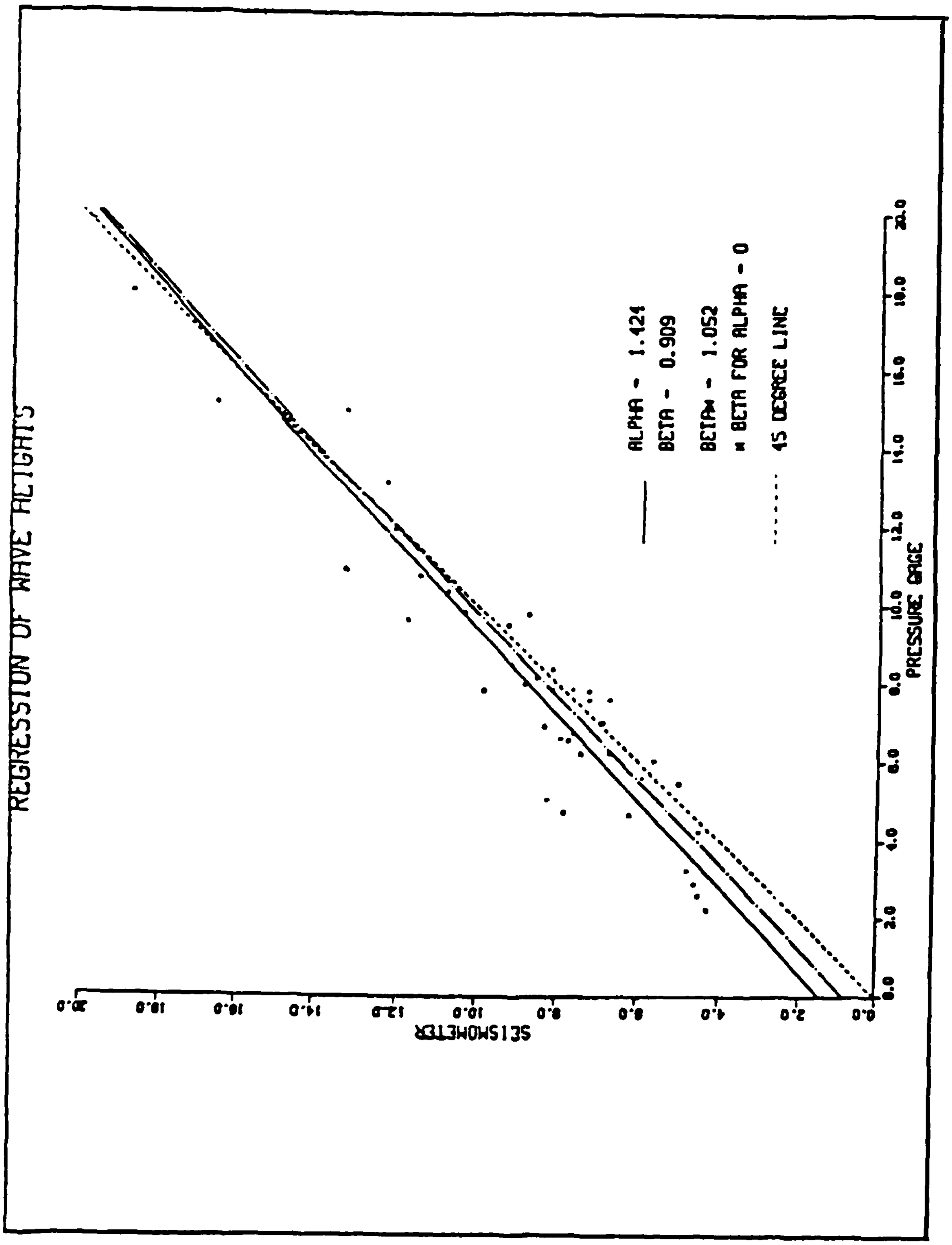

TIME SERIES OF WAVE PERIODS
PRESSURE GAGE
SEISMOMETER
TIME(DAYS)
WAVE PERIOD(SECONDS)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 2



REGRESSION OF WAVE HEIGHTS
ALPHA - 1.424
BETA - 0.909
BETA* - 1.052
* BETA FOR ALPHA - 0
45 DEGREE LINE
PRESSURE GAGE
SEISMOMETER
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 3

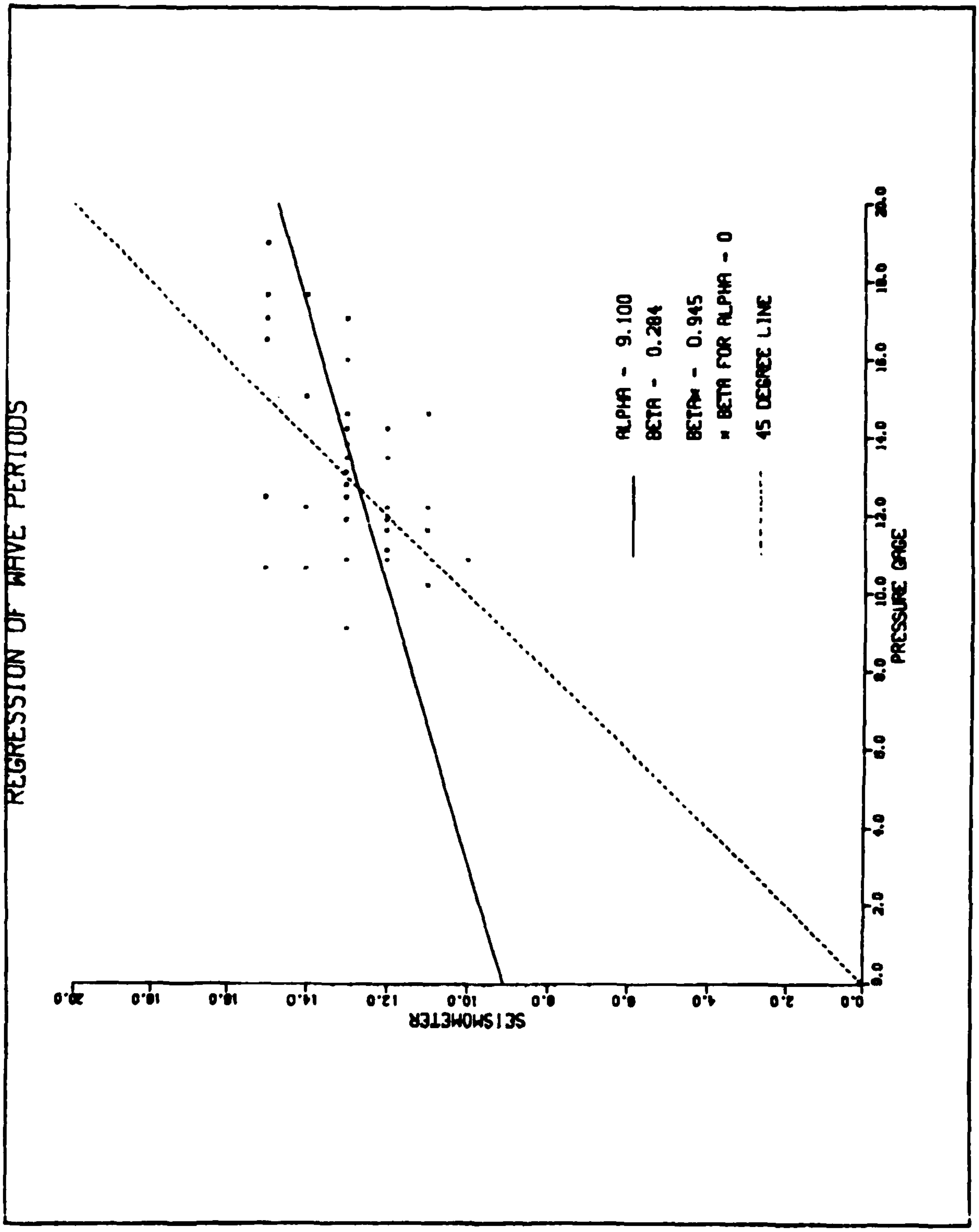

REGRESSION OF WAVE PERIODS
SEISMOMETER
PRESSURE GAGE
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
ALPHA - 9.100
BETA - 0.284
BETA* - 0.945
* BETA FOR ALPHA - 0
45 DEGREE LINE

PLATE 4

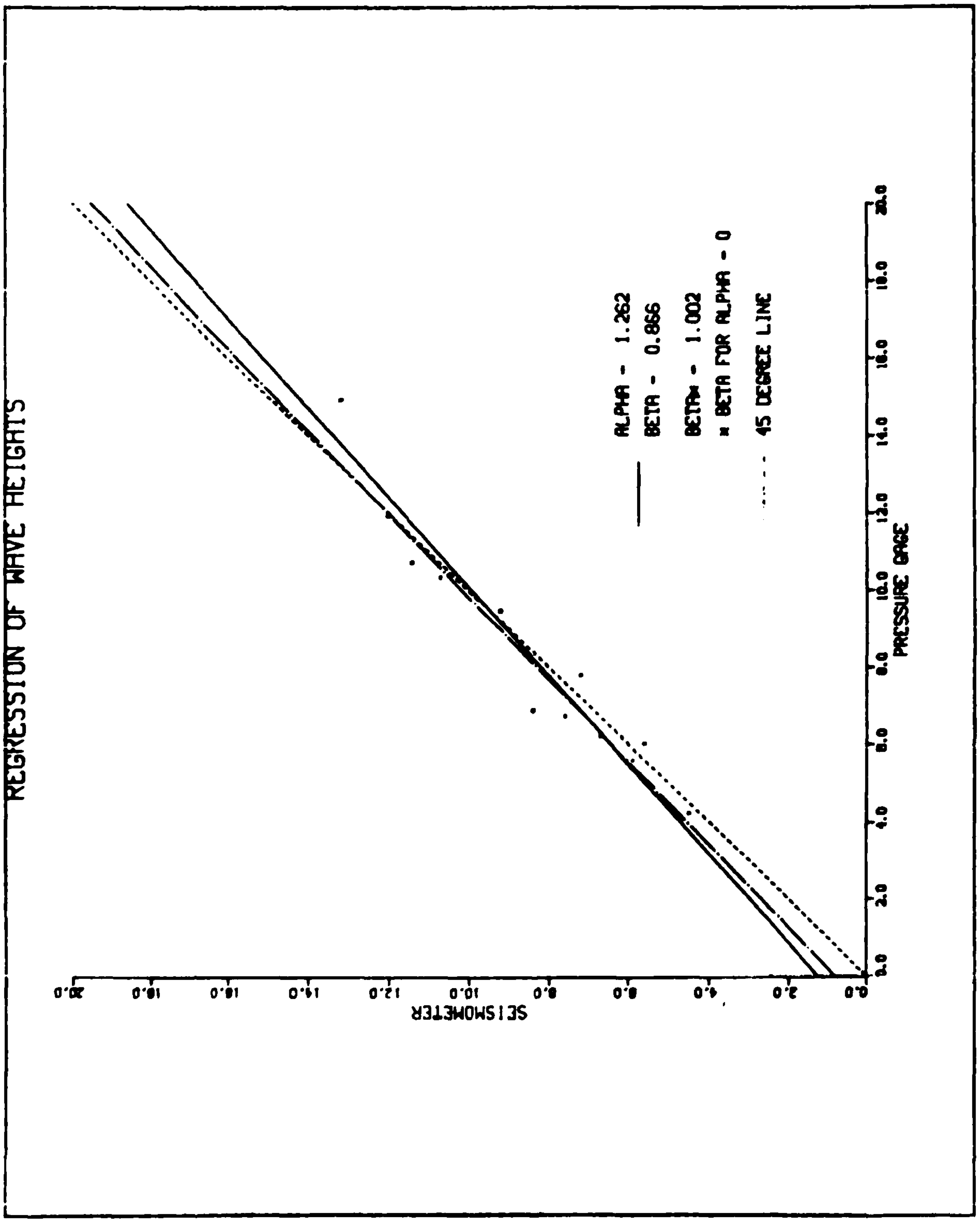

REGRESSION OF WAVE HEIGHTS
ALPHA - 1.262
BETA - 0.866
BETA* - 1.002
* BETA FOR ALPHA - 0
45 DEGREE LINE
PRESSURE GAGE
SEISMOMETER
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 5

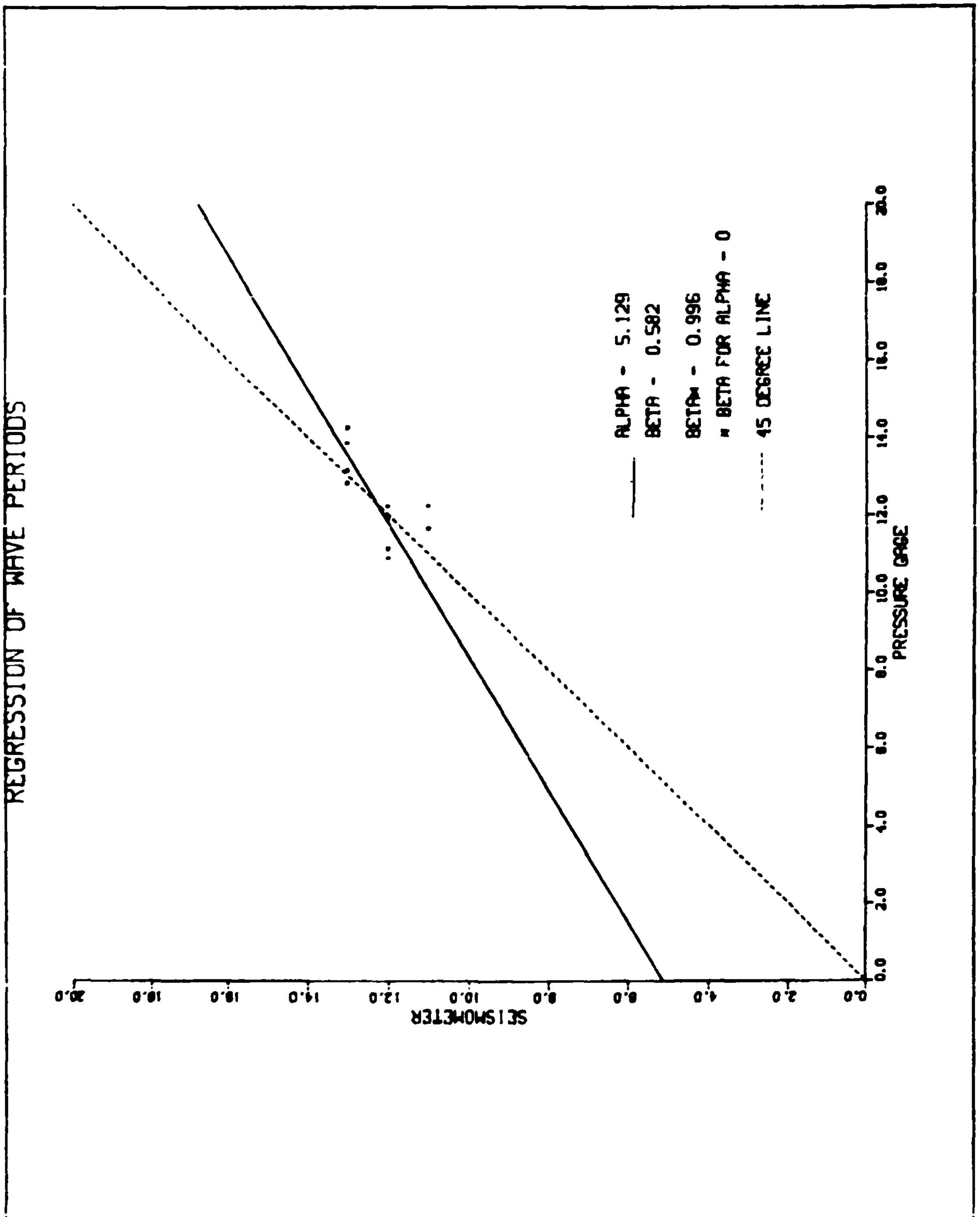

REGRESSION OF WAVE PERIODS
ALPHA - 5.129
BETA - 0.582
BETA* - 0.996
* BETA FOR ALPHA - 0
45 DEGREE LINE
PRESSURE GAGE
SEISMOMETER
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 6

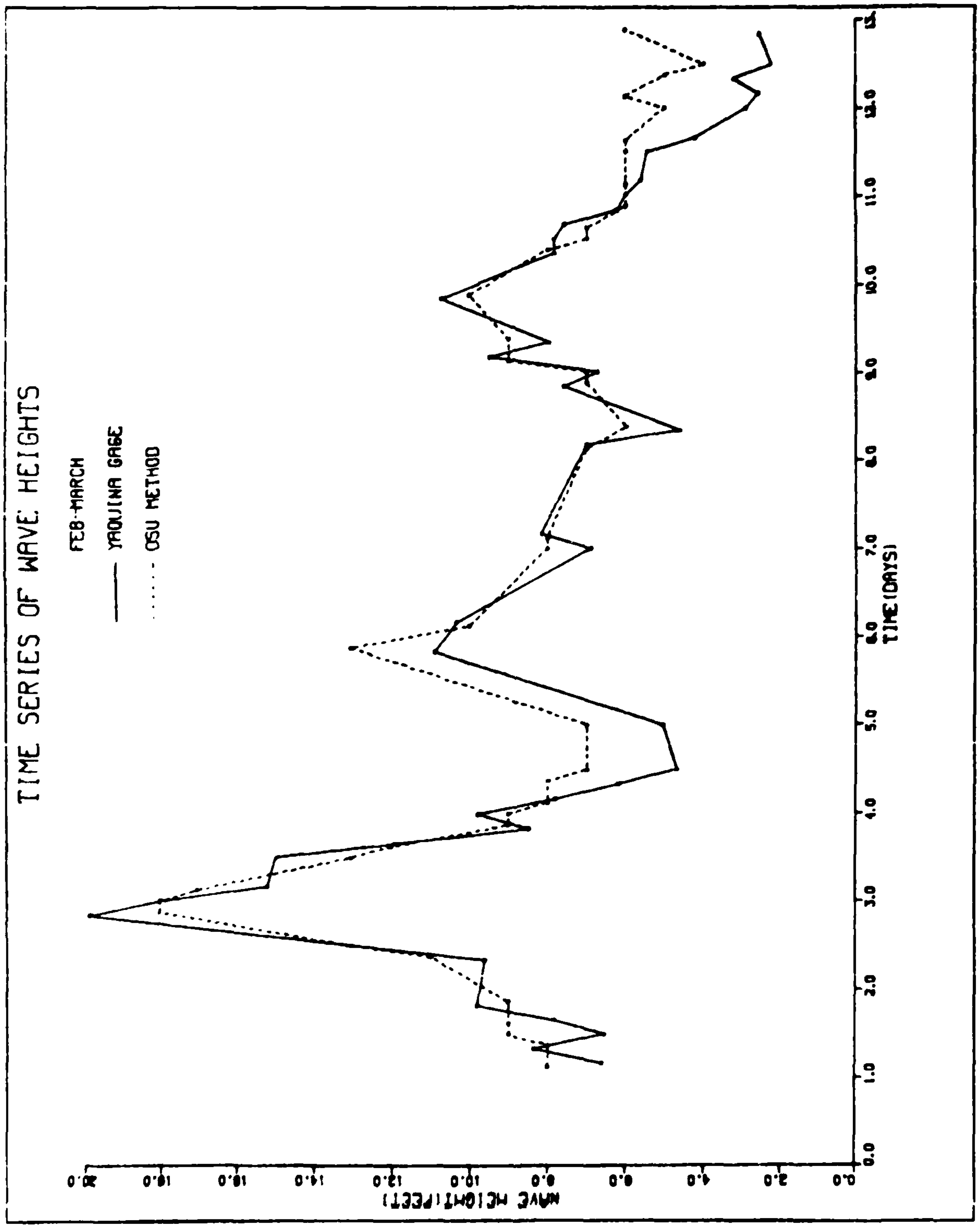

TIME SERIES OF WAVE HEIGHTS
FEB-MARCH
YAQUINA GAGE
OSU METHOD
TIME(DAYS)
WAVE HEIGHT(FEET)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 7

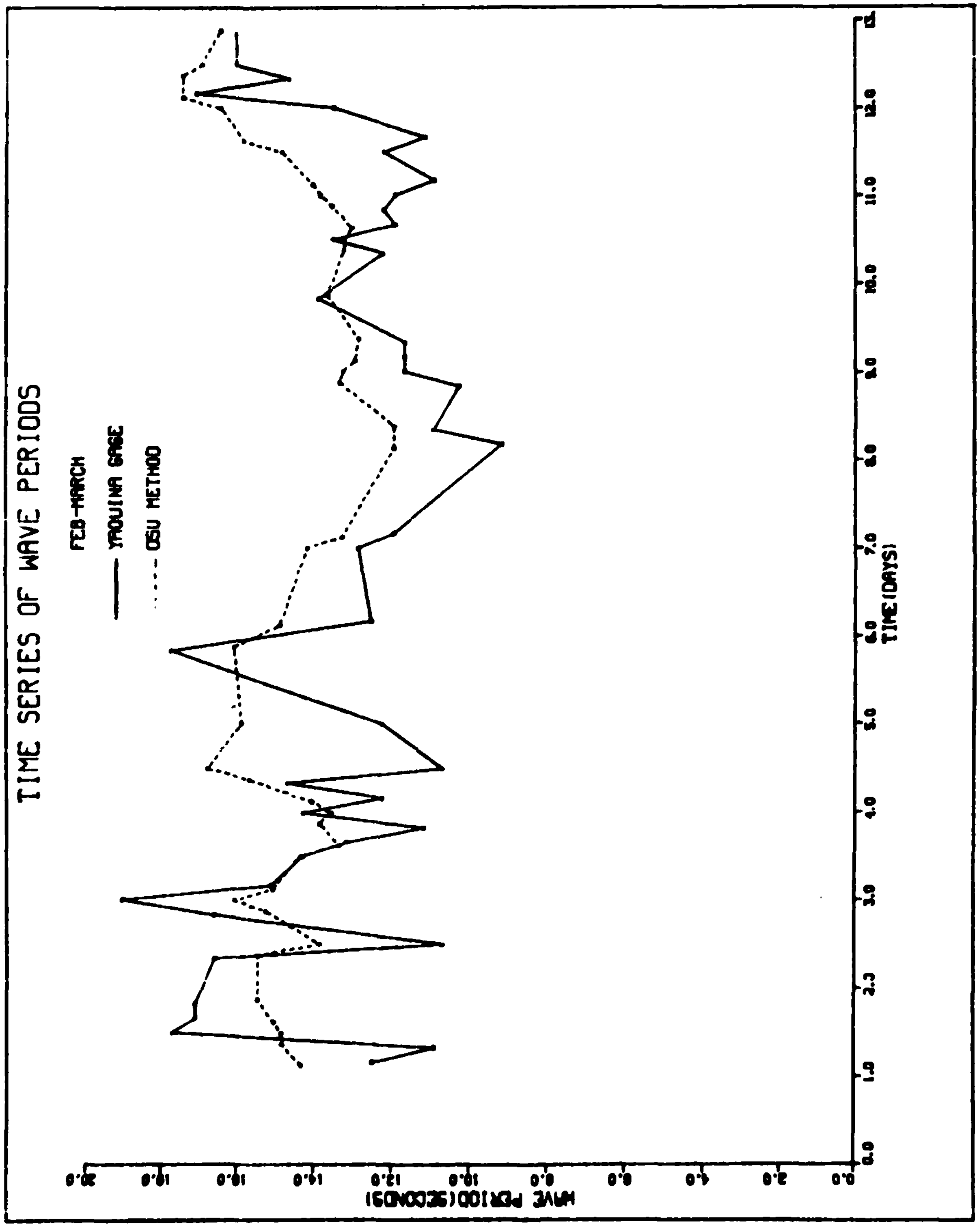

TIME SERIES OF WAVE PERIODS
FEB-MARCH
YAQUINA GAGE
OSU METHOD
TIME(DAYS)
WAVE PERIOD(SECONDS)

PLATE 8

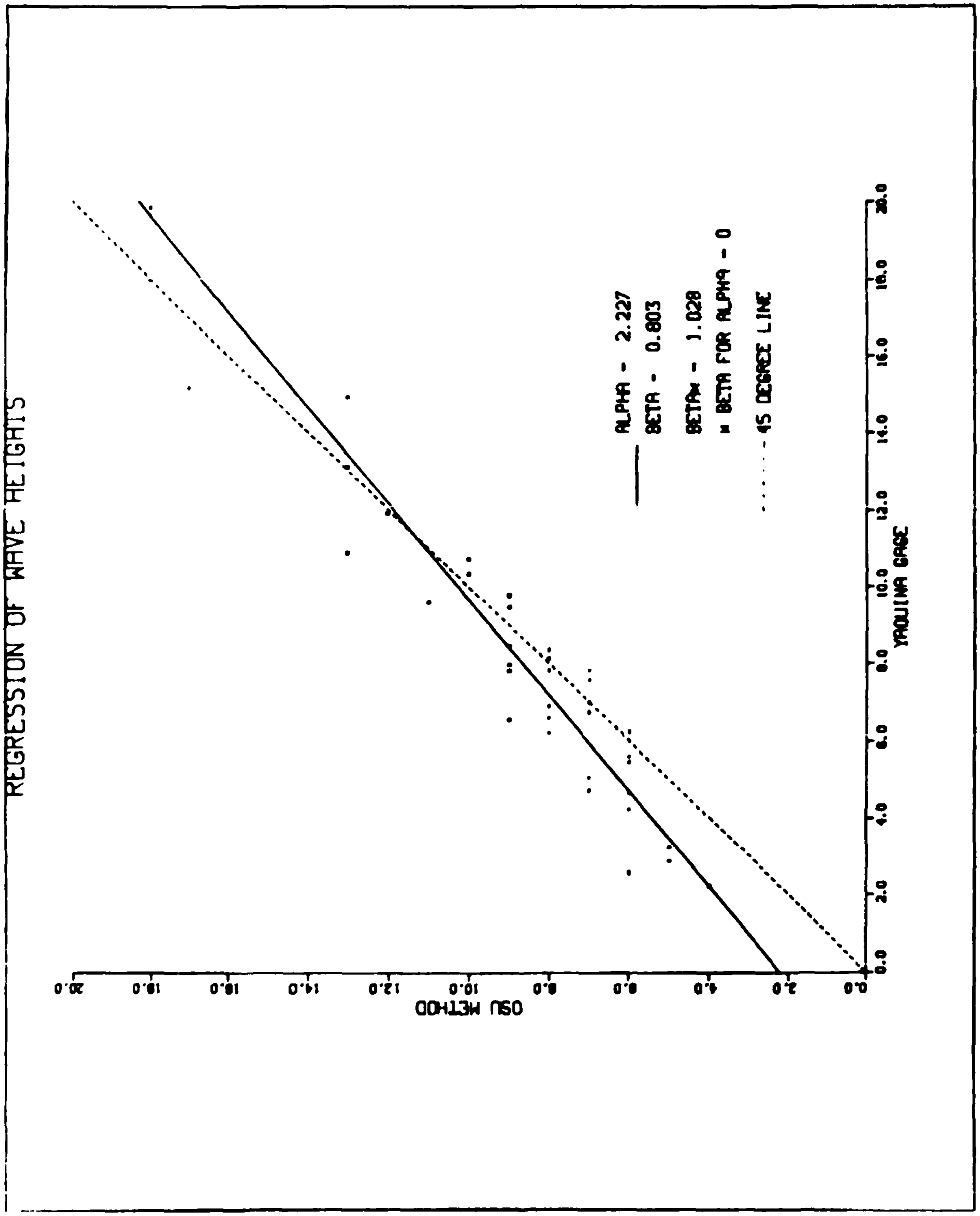

REGRESSION OF WAVE HEIGHTS
ALPHA - 2.227
BETA - 0.803
BETA* - 1.028
* BETA FOR ALPHA - 0
45 DEGREE LINE
YAQUINA GAGE
OSU METHOD
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 9

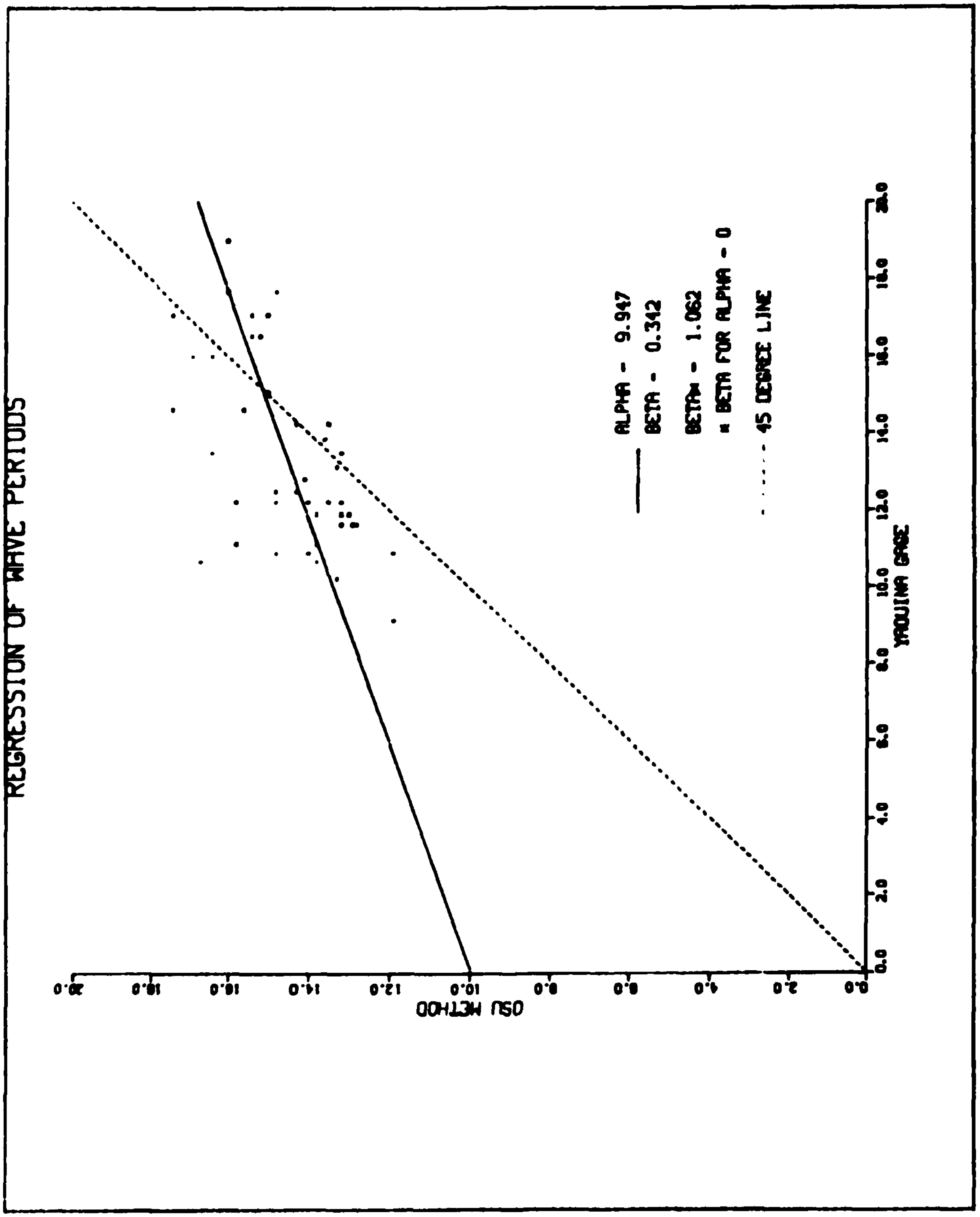
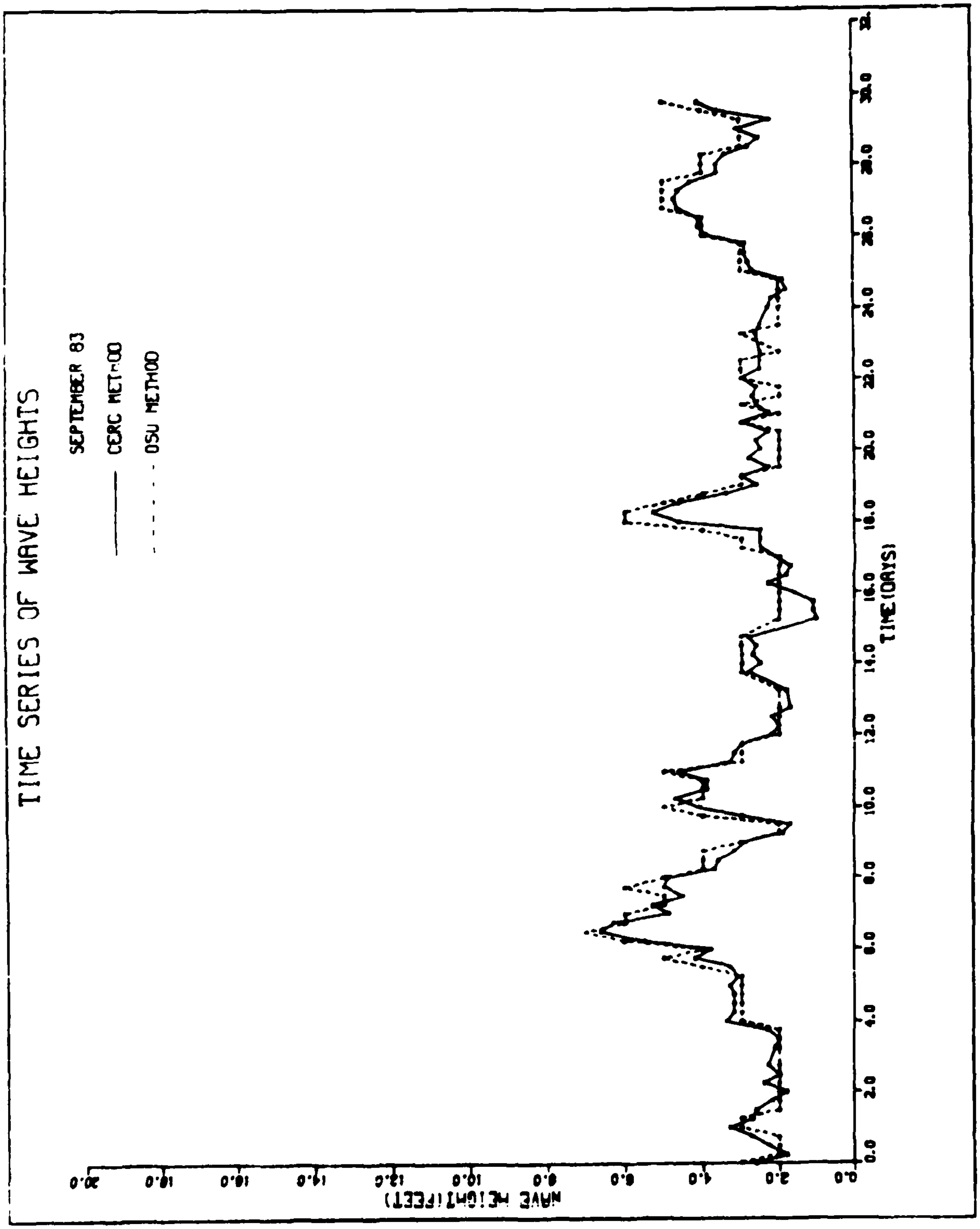

REGRESSION OF WAVE PERIODS
ALPHA - 9.947
BETA - 0.342
BETA* - 1.062
* BETA FOR ALPHA - 0
45 DEGREE LINE
OSU METHOD
YAQUINA GAGE
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 10



TIME SERIES OF WAVE HEIGHTS
SEPTEMBER 83
CERC MET-OD
OSU METHOD
WAVE HEIGHT(FEET)
TIME(DAYS)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
32.

PLATE 11

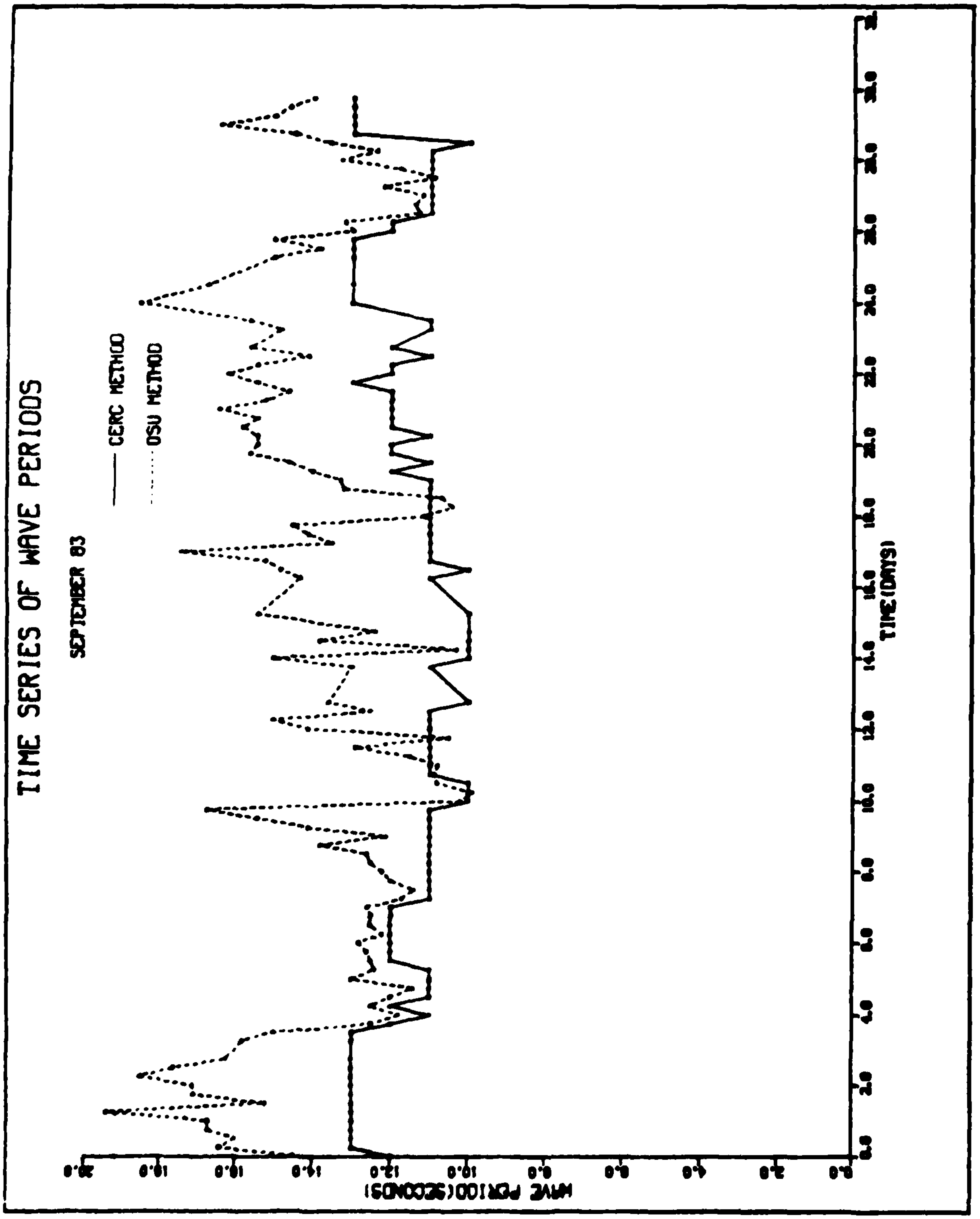

TIME SERIES OF WAVE PERIODS
SEPTEMBER 83
CERC METHOD
OSU METHOD
TIME(DAYS)
WAVE PERIOD(SECONDS)

PLATE 12

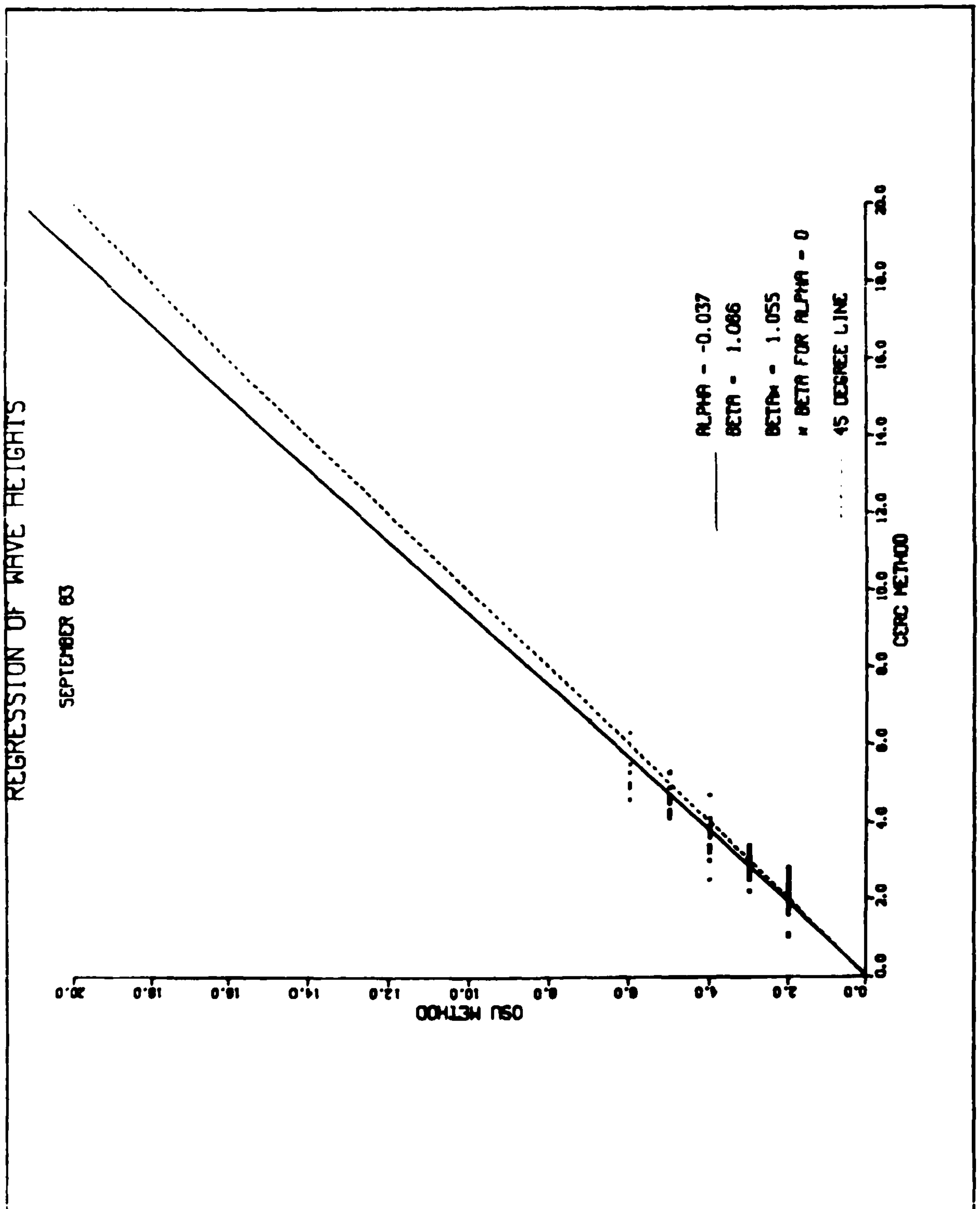
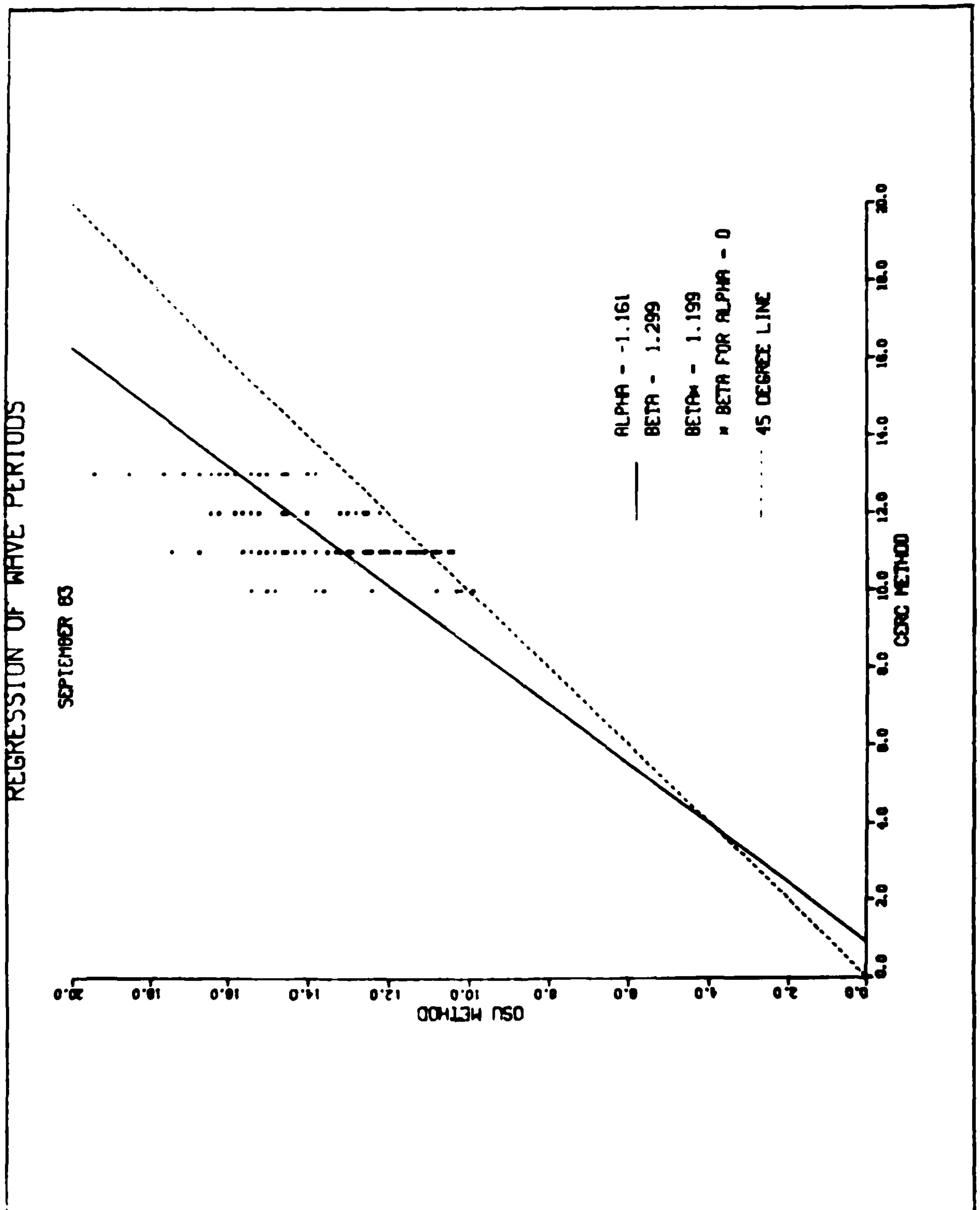

REGRESSION OF WAVE HEIGHTS
SEPTEMBER 83
ALPHA = -0.037
BETA = 1.086
BETA* = 1.055
* BETA FOR ALPHA = 0
45 DEGREE LINE
CERC METHOD
OSU METHOD

PLATE 13



REGRESSION OF WAVE PERIODS
SEPTEMBER 83
ALPHA = -1.161
BETA = 1.299
BETA* = 1.199
* BETA FOR ALPHA = 0
45 DEGREE LINE
CERC METHOD
OSU METHOD
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 14

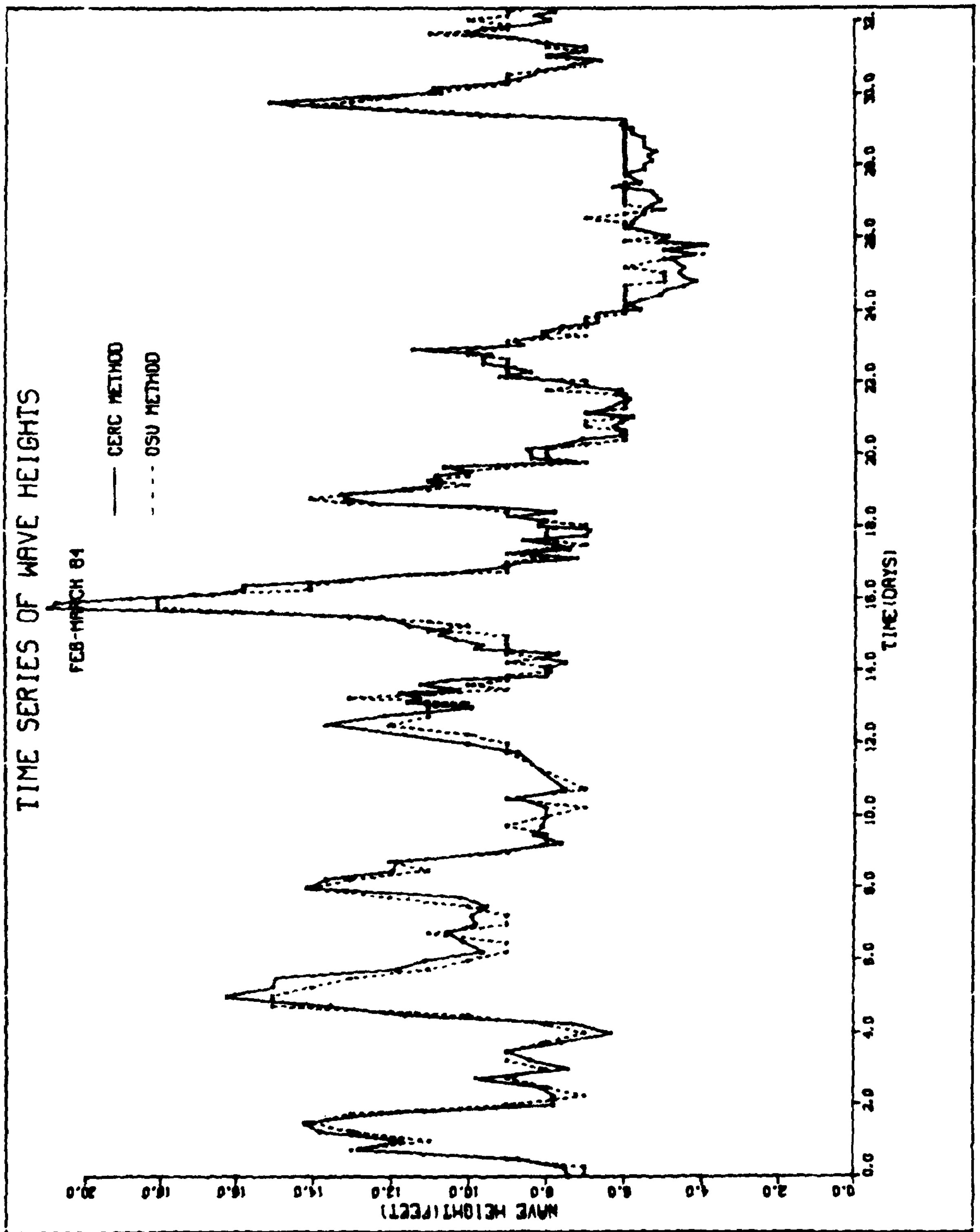

TIME SERIES OF WAVE HEIGHTS
FEB-MARCH 84
CERC METHOD
OSU METHOD
TIME(DAYS)
WAVE HEIGHT(FEET)

PLATE 15

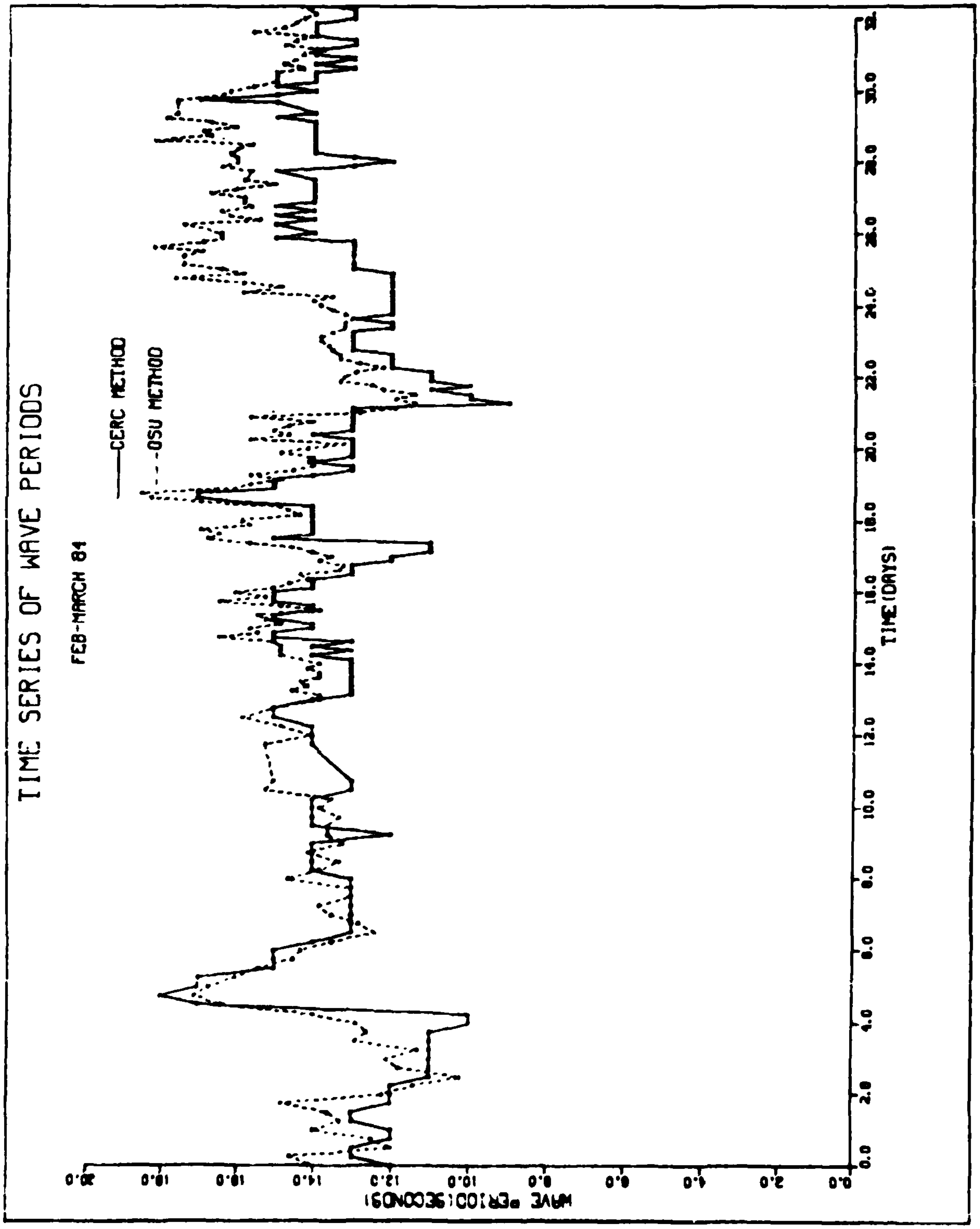

TIME SERIES OF WAVE PERIODS
FEB-MARCH 84
CERC METHOD
OSU METHOD
TIME(DAYS)
WAVE PERIOD(SECONDS)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
30.0
32
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 16

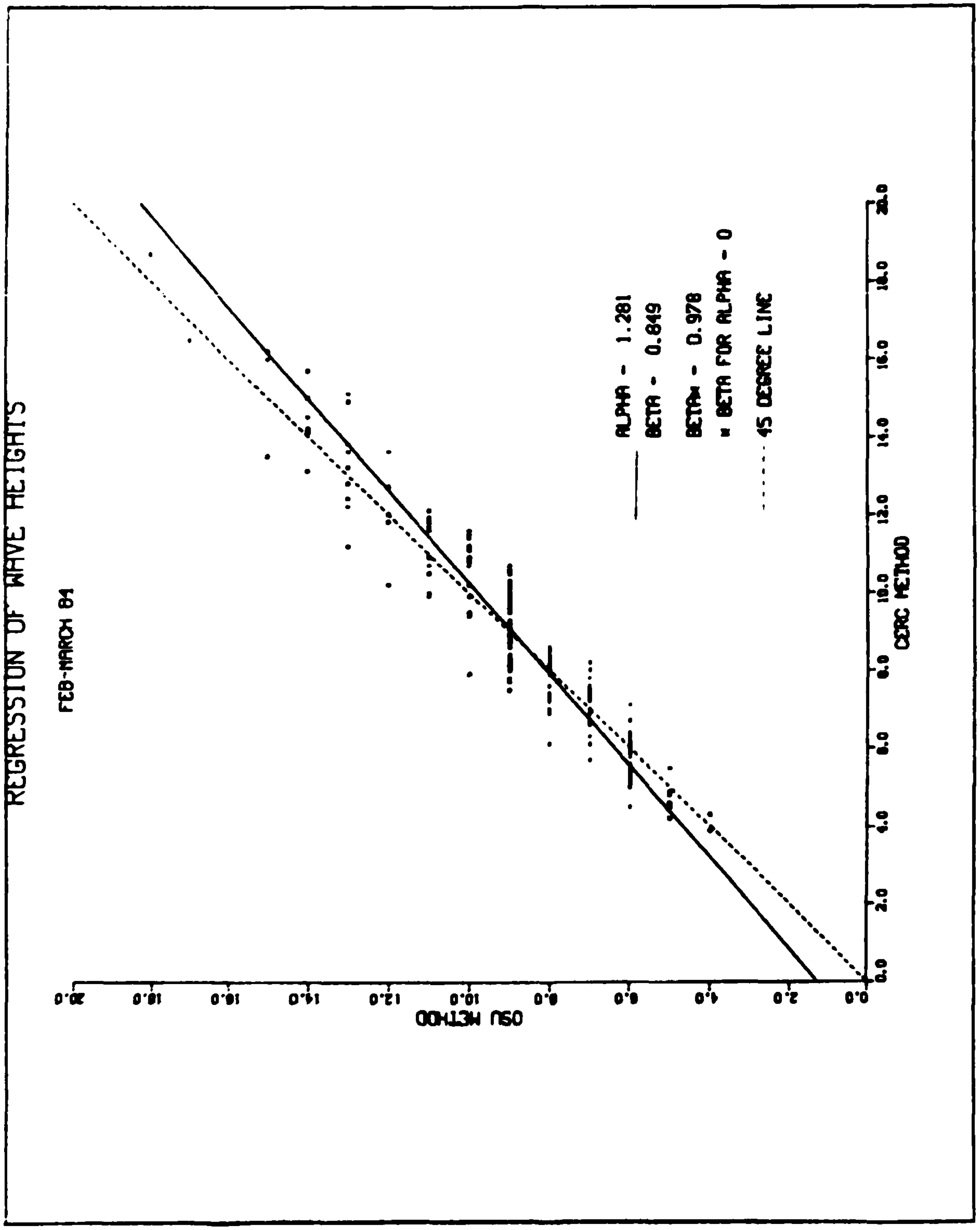

REGRESSION OF WAVE HEIGHTS
FEB-MARCH 84
ALPHA - 1.281
BETA - 0.849
BETA* - 0.978
* BETA FOR ALPHA - 0
45 DEGREE LINE
CERC METHOD
OSU METHOD
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 17

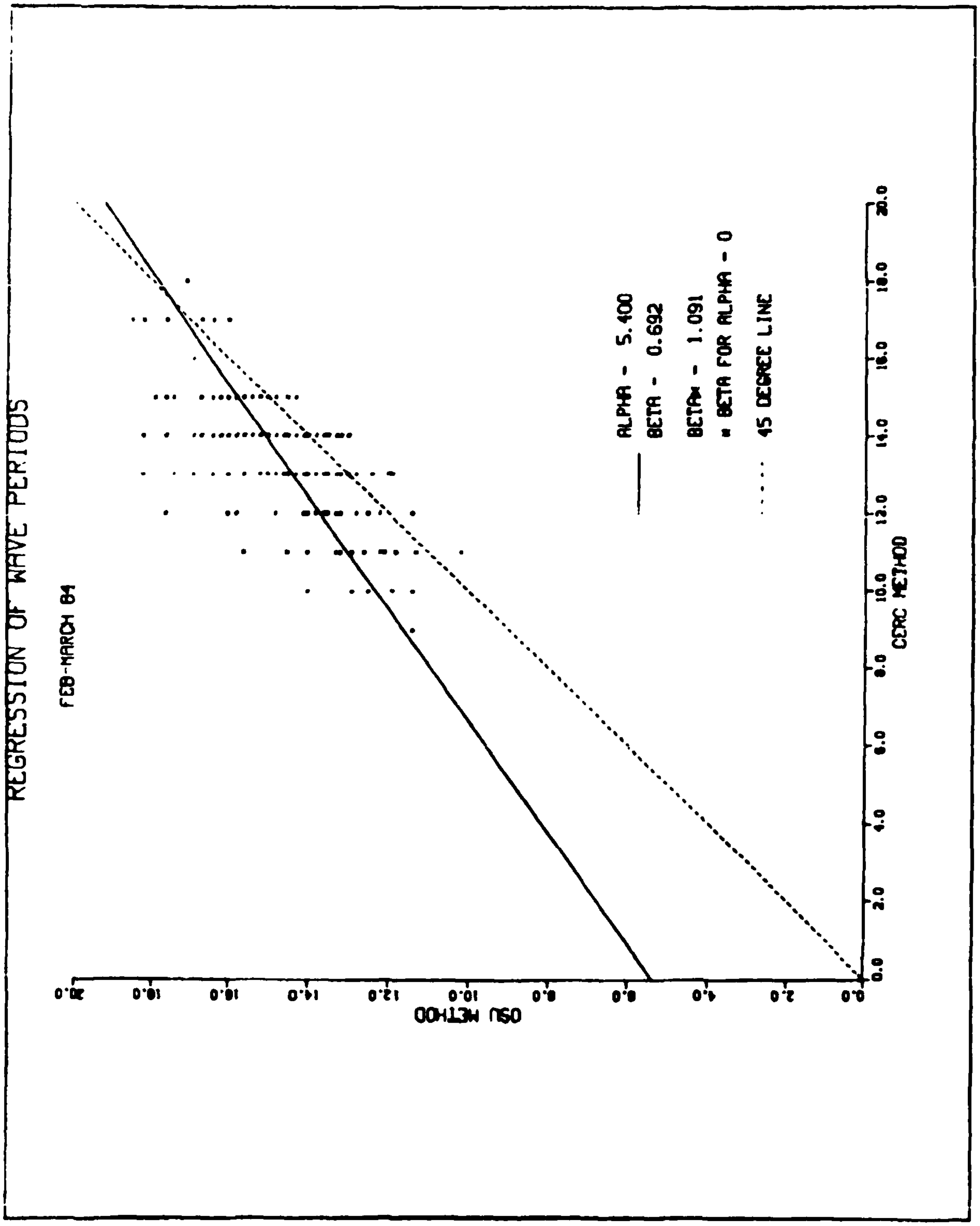
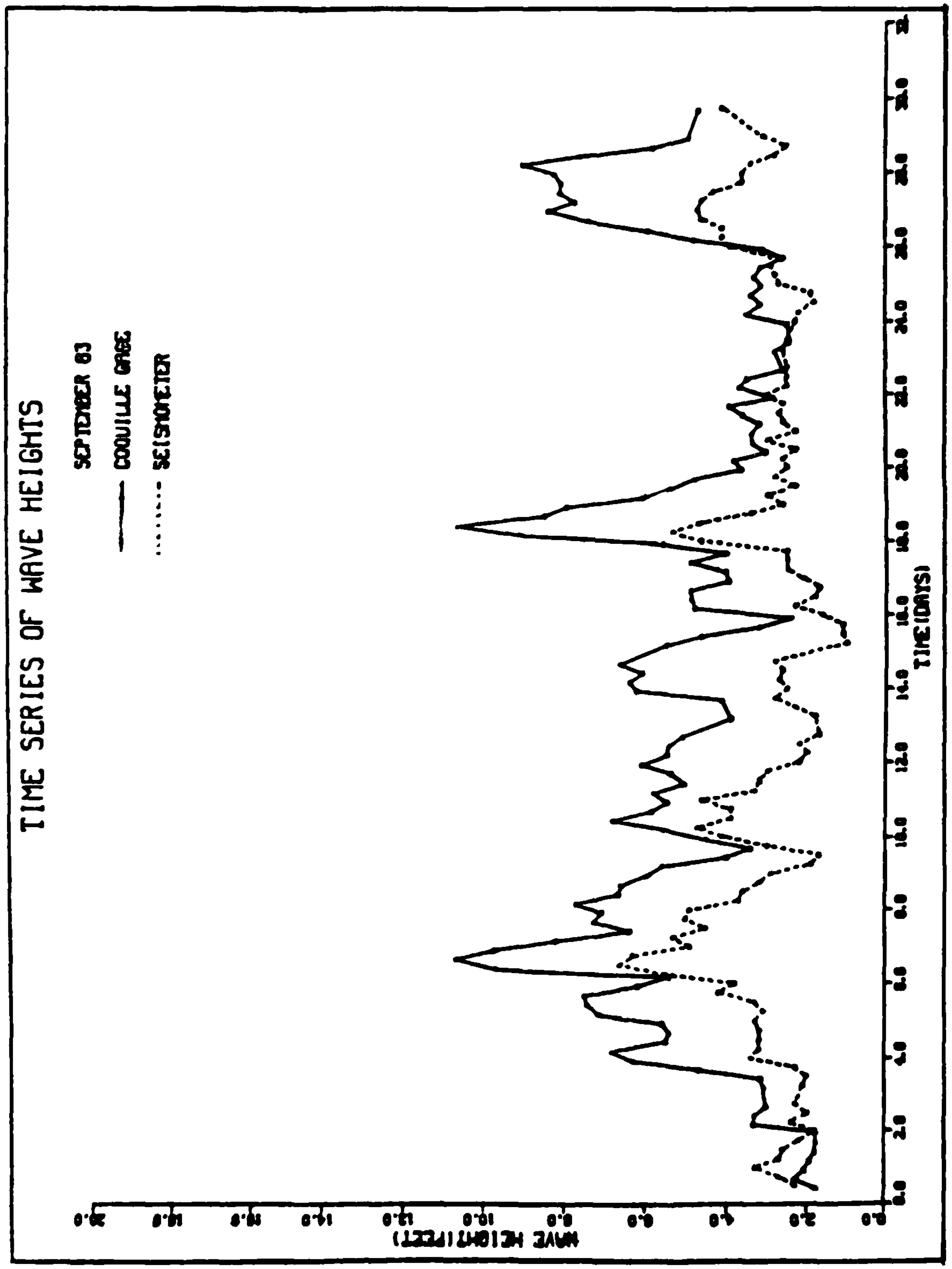

REGRESSION OF WAVE PERIODS
FEB-MARCH 84
ALPHA - 5.400
BETA - 0.692
BETA* - 1.091
* BETA FOR ALPHA - 0
45 DEGREE LINE
CERC METHOD
OSU METHOD

PLATE 18



TIME SERIES OF WAVE HEIGHTS
SEPTEMBER 83
COQUILLE GAGE
SEISMOMETER
TIME(DAYS)
WAVE HEIGHT(FEET)

PLATE 19

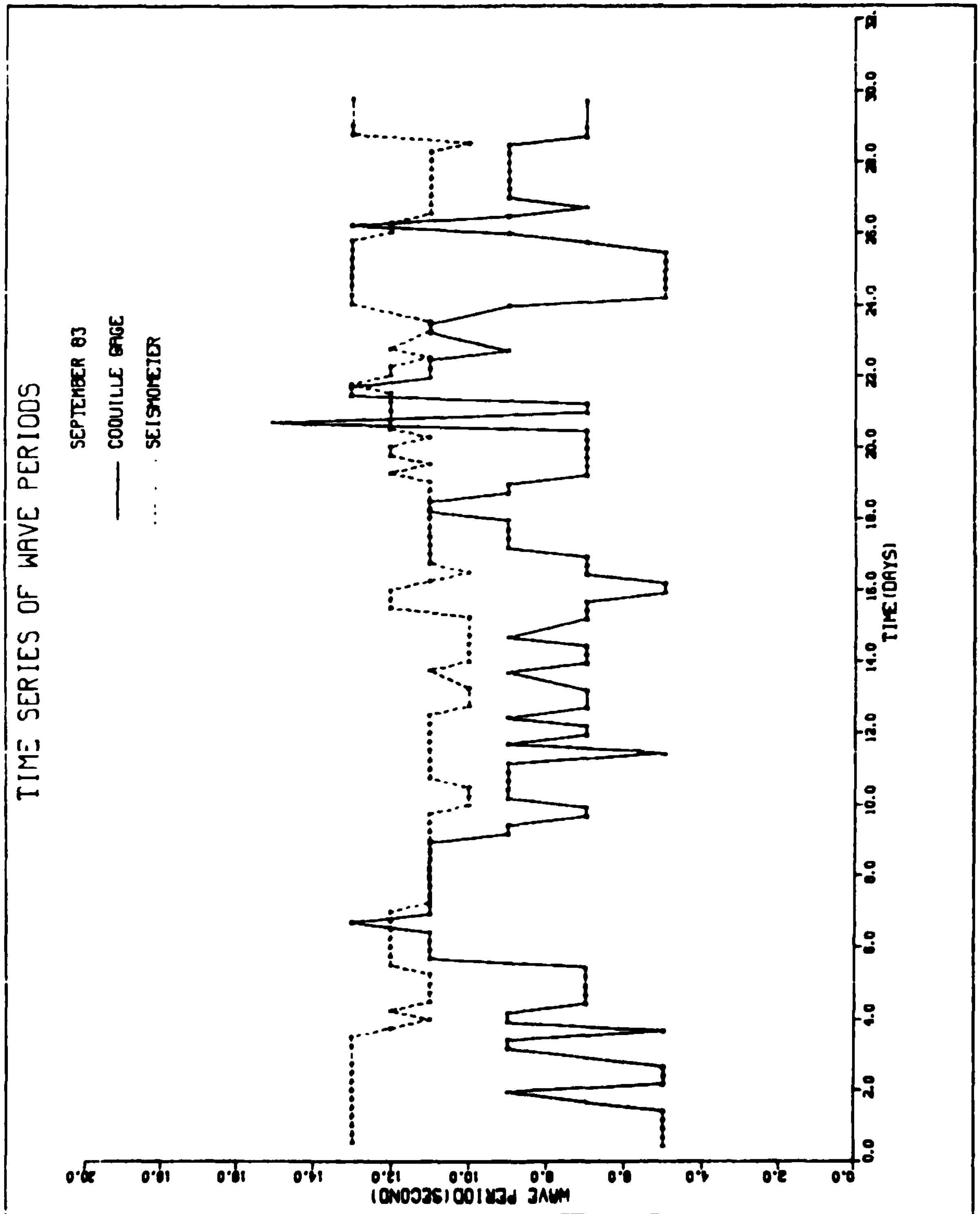
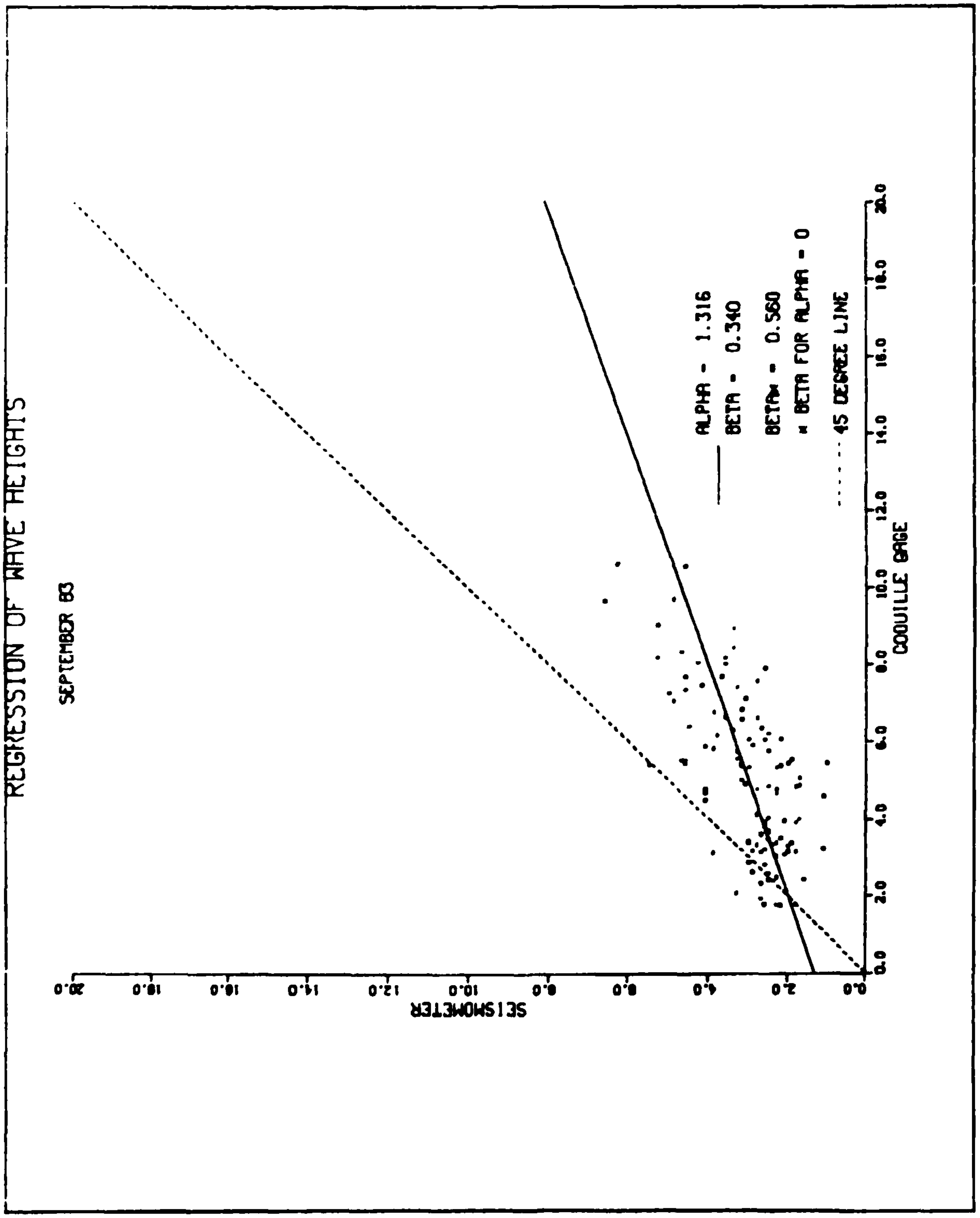
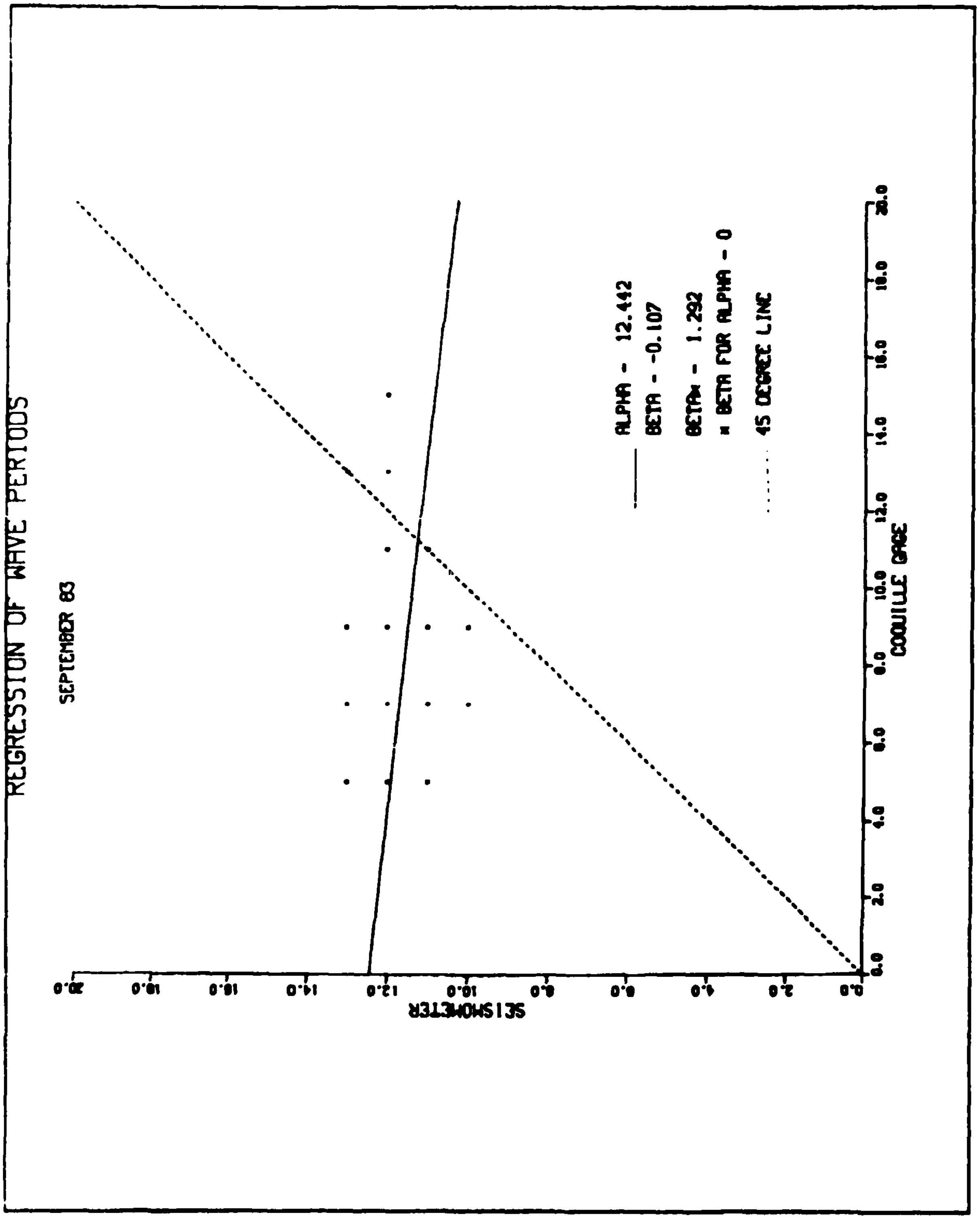

TIME SERIES OF WAVE PERIODS
SEPTEMBER 83
COQUILLE GAGE
SEISMOMETER
TIME(DAYS)
WAVE PERIOD(SECOND)

PLATE 20



REGRESSION OF WAVE HEIGHTS
SEPTEMBER 83
ALPHA - 1.316
BETA - 0.340
BETA* - 0.560
* BETA FOR ALPHA - 0
45 DEGREE LINE
SEISMOMETER
COQUILLE GAGE
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 21



REGRESSION OF WAVE PERIODS
SEPTEMBER 83
ALPHA - 12.442
BETA - -0.107
BETA* - 1.292
* BETA FOR ALPHA - 0
45 DEGREE LINE
COQUILLE GAGE
SEISMOMETER
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 22

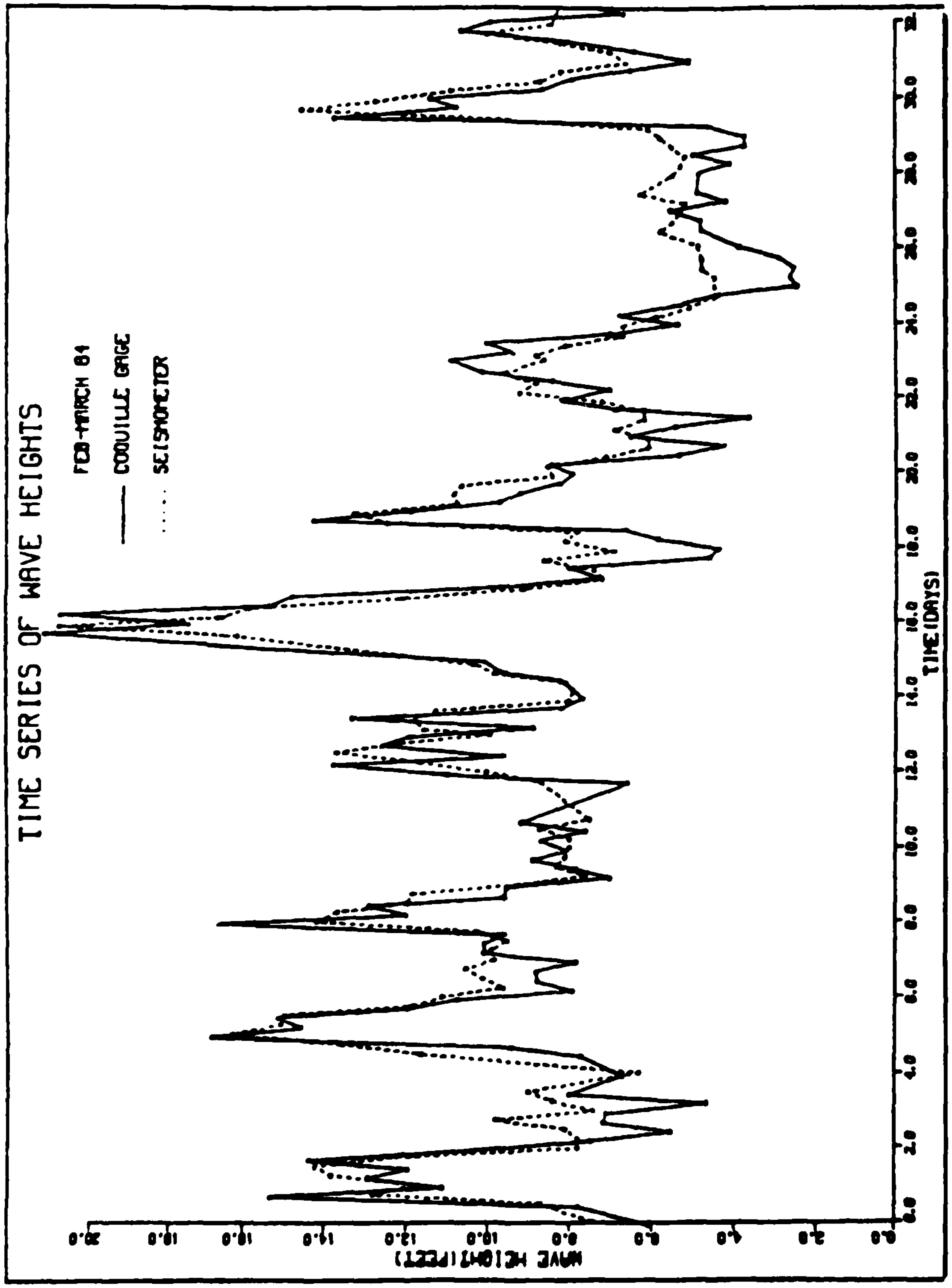

TIME SERIES OF WAVE HEIGHTS
FEB-MARCH 84
COQUILLE GAGE
SEISMOMETER
TIME(DAYS)
WAVE HEIGHT(FEET)

PLATE 23

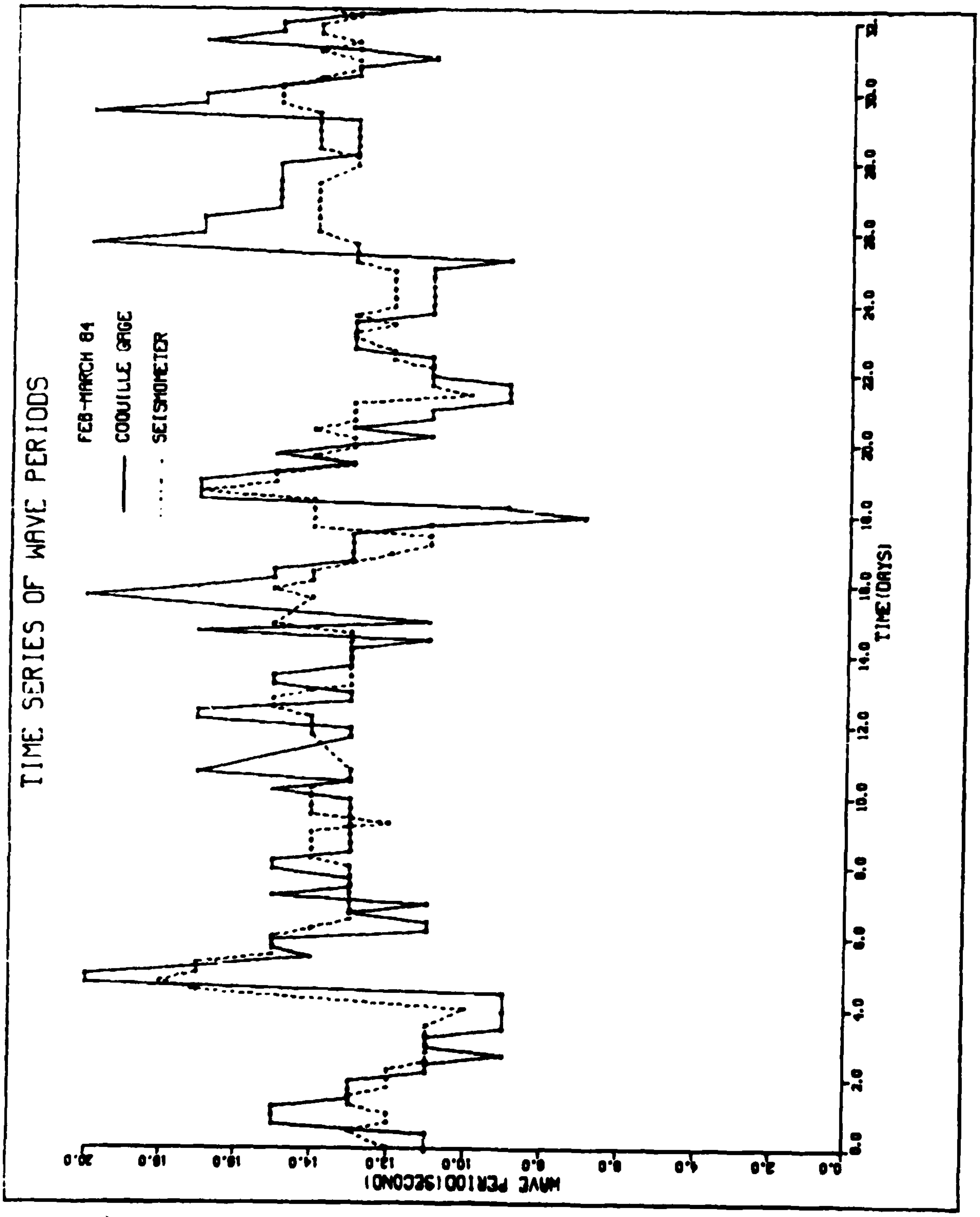
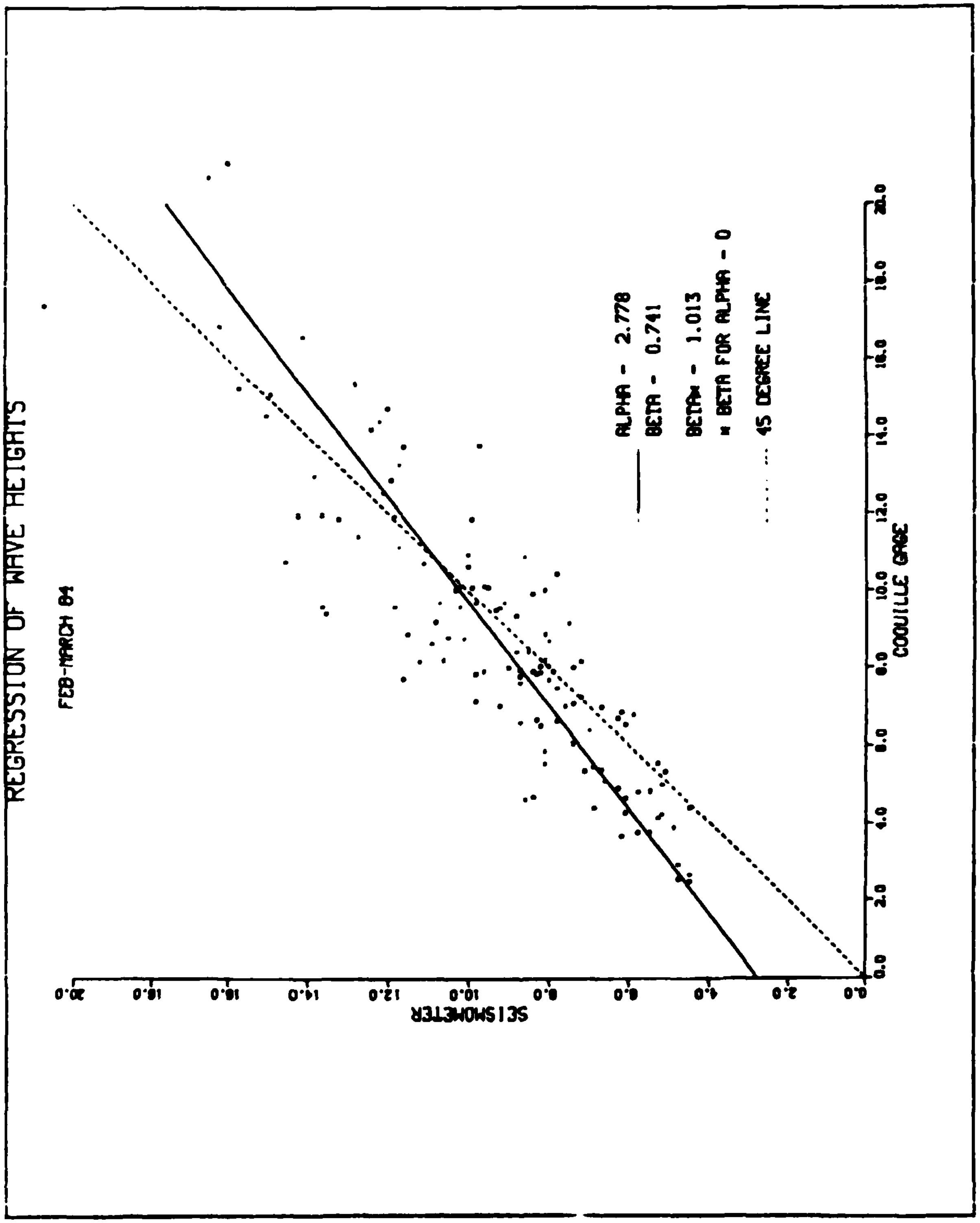
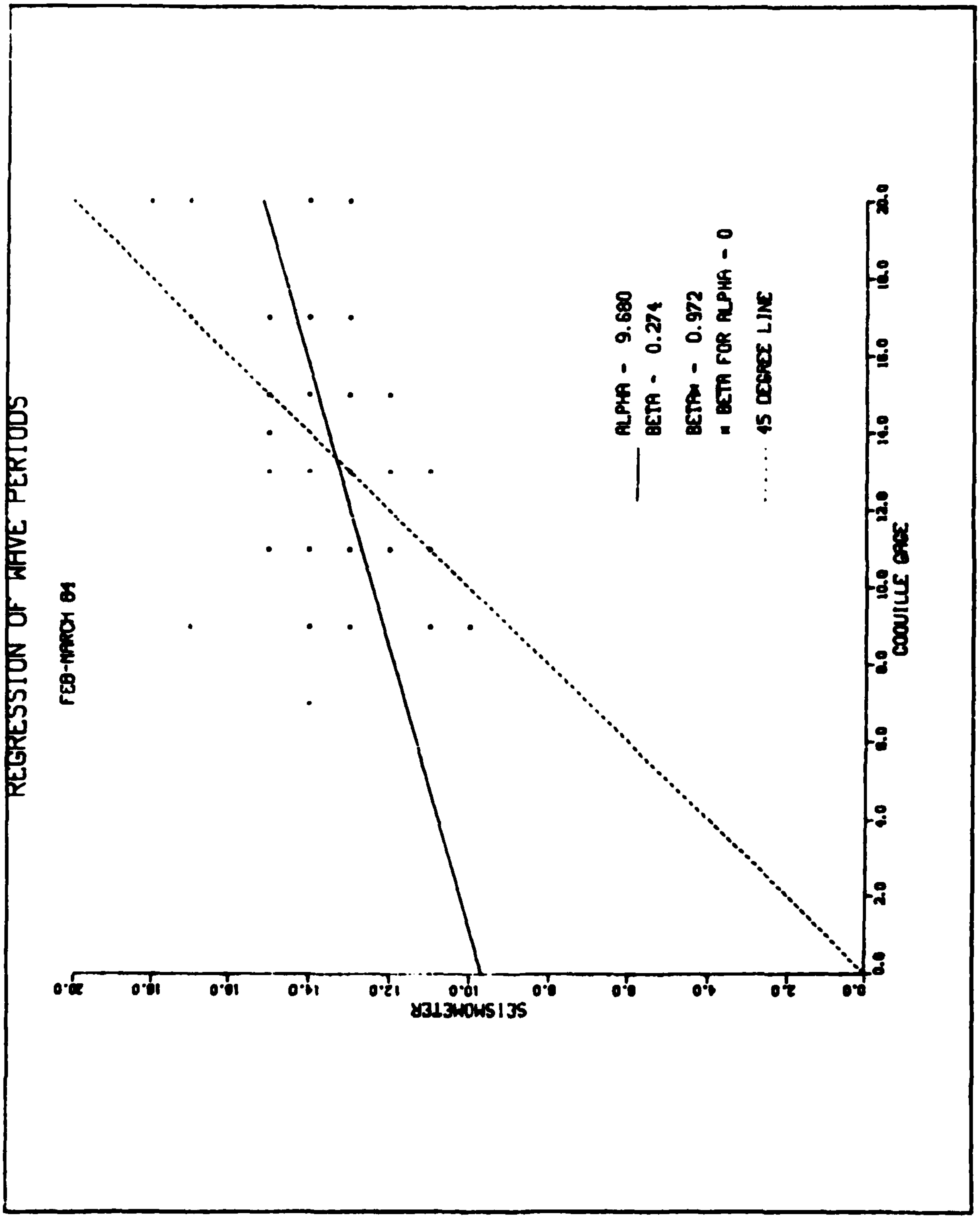

TIME SERIES OF WAVE PERIODS
FEB-MARCH 84
COQUILLE GAGE
SEISMOMETER
TIME(DAYS)
WAVE PERIOD(SECOND)

PLATE 24



REGRESSION OF WAVE HEIGHTS
FEB-MARCH 84
ALPHA - 2.778
BETA - 0.741
BETA* - 1.013
* BETA FOR ALPHA - 0
45 DEGREE LINE
SEISMOMETER
COQUILLE GAGE
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 25



REGRESSION OF WAVE PERIODS
FEB-MARCH 84
ALPHA - 9.680
BETA - 0.274
BETA* - 0.972
* BETA FOR ALPHA - 0
45 DEGREE LINE
COQUILLE GAGE
SEISMOMETER
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0

PLATE 26

APPENDIX A: CERC PROCEDURE FOR ANALYSIS OF WAVE DATA

1. The following procedure was used for analysis of the wave data from 10-min pen-and-ink seismometer records (based on a Rayleigh distribution for wave heights):

   a. Run the period template (Figure A1) along the 10-min record until a group of fairly uniform waves, which should contain some of the highest waves, is found.

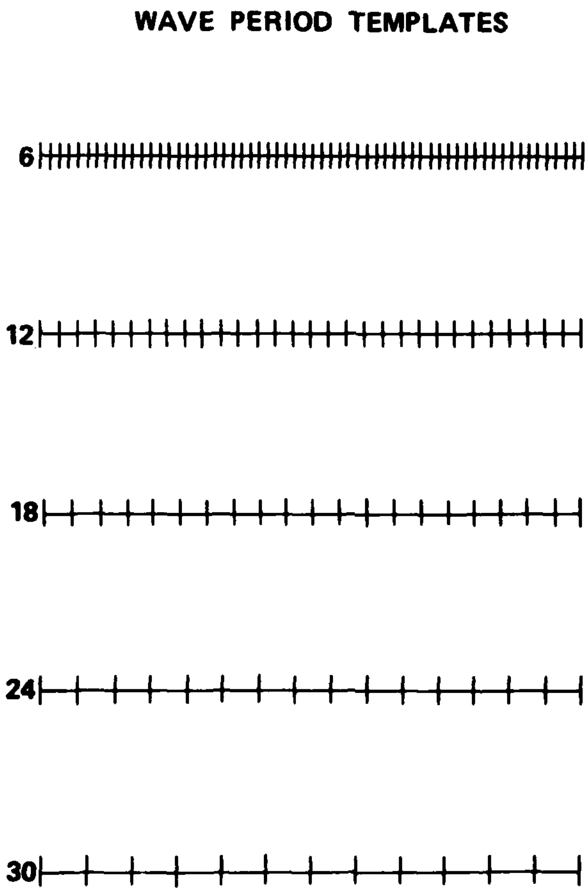


Figure A1. Wave period template for seismometer records with recorder speed of 1 in. per min (not to scale) (period readings are in seconds)

   b. Determine the appropriate period of the waves selected in a by using the template according to instructions. When the wave period on the chart falls between two of the periods shown on the template, the analyzer may approximate what is considered to be nearest to the exact period; e.g., if the period is longer

than the 12-sec period and shorter than the 18-sec period by about the same amount, the period must be about 15 sec.

c. Use Table A1 to determine which wave should be measured in the full 10-min record to get the approximate significant height of the waves. The wave number is determined by calling the highest wave in the full 10-min record wave number 1; the second highest wave is number 2, etc.

Table A1

Analysis Procedure for 10-Min Seismometer Record

Wave Period sec	Number of Wave To Measure
6	13
7	11
8	10
9	9
10	8
11	7
12	7
13	6
14	6
15	5
16	5
17	5
18	4
19	4
20	4

d. Determine the height of the wave given by c in terms of feet and tenths. Wave height is determined as follows. Wave height is equal to the average of the height of two successive waves in the seismometer record. Use the height template (Figure A2) to estimate each height measured from crest to left-hand (following) trough. Note each wave height in pencil above the crest. Note the average height of two successive seismometer waves in pencil above the crests. The procedure is illustrated in Figure A3.

e. Tabulate month, day, year, beginning time of record, significant wave height, and significant period.

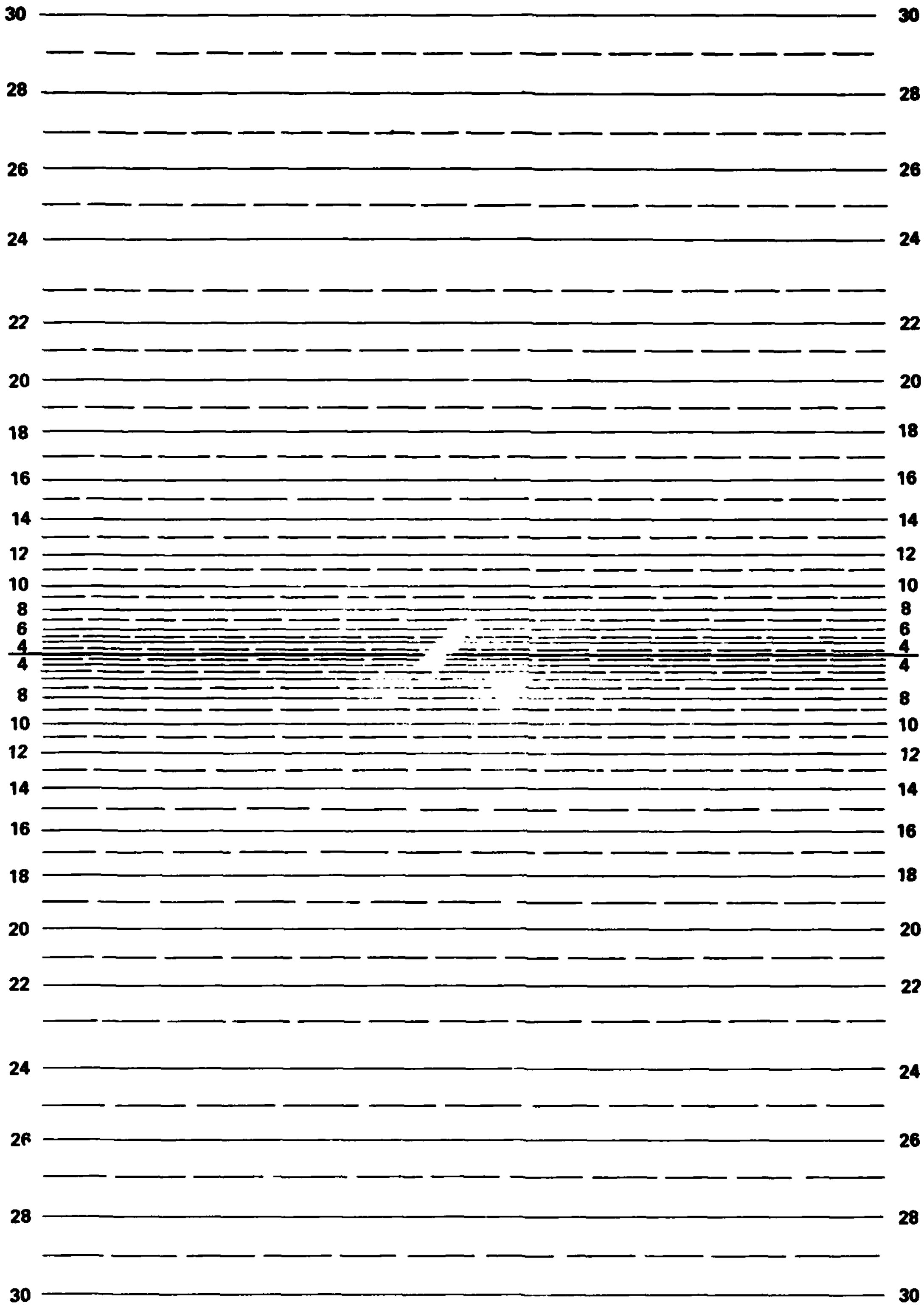


Figure A2. Wave height template for seismometer records with scale equal to 1.0 (not to scale) (height readings are in feet)

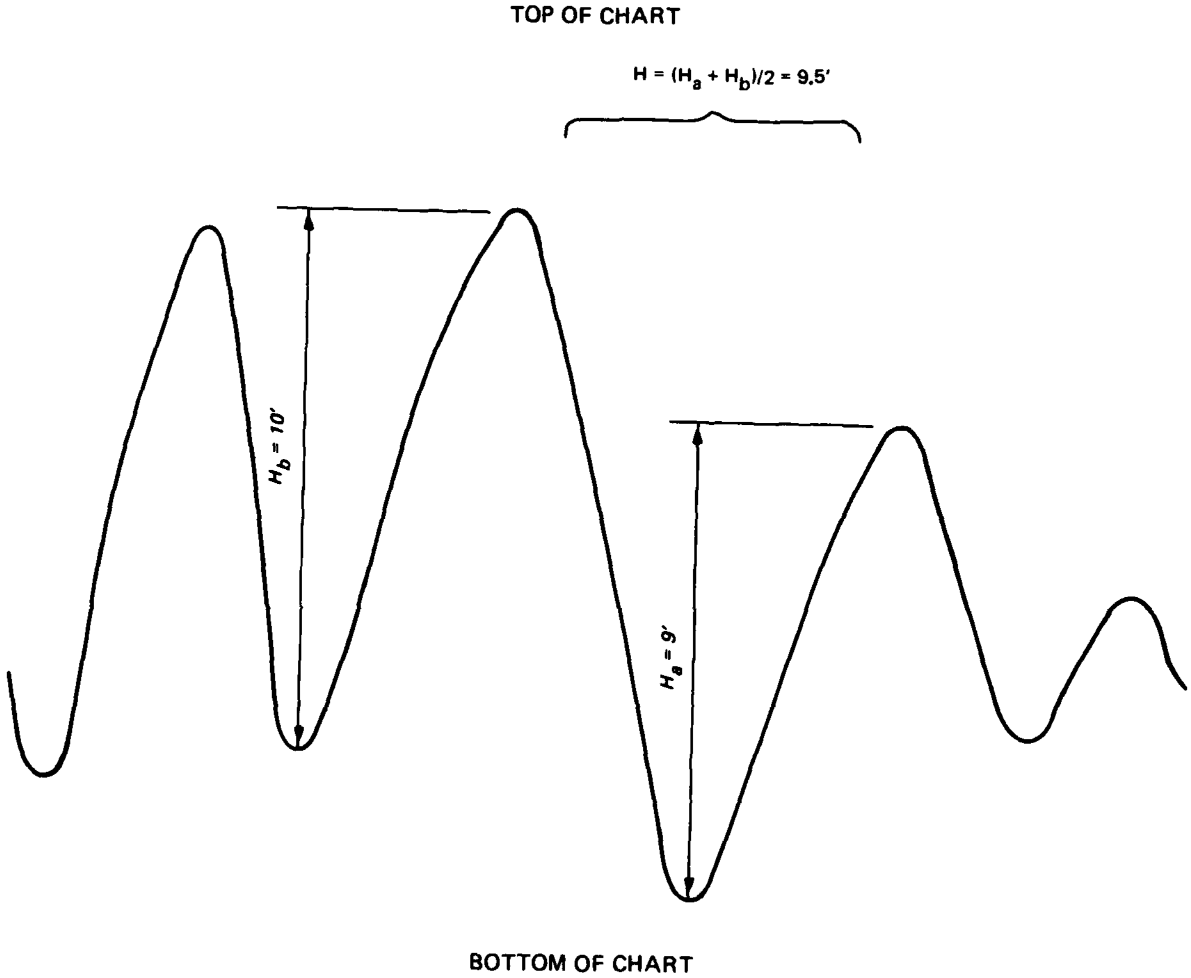


Figure A3. Procedure for estimating ocean wave height from seismometer wave records

END

FILMED

2-86

DTIC